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A

# LABORATORY MANUAL

OF

# ELECTROTHERAPEUTICS

BY

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## PREFACE.

For a number of years the opportunity has been given the students in the Department of Medicine and Surgery of the University of Michigan to learn the relation which electricity bears to physiological action and the rational application of that action to therapeutics.

For some years attendance upon the course of instruction offered in this branch was optional with the student. But so great has been the accumulation of knowledge concerning the part electricity plays in the movements of both animate and inanimate things, and so important a part is it found to take in determining these movements that it can no longer be excluded from a curriculum of study for medical students that aims to be thorough and complete.

In the study of influences which affect the animal economy, beneficially or otherwise, it is quite as essential that we know the part due to electric action as to know what is due to chemism or to radiant energy in the form of light and heat.

It has been our experience that the knowledge required by the student of medicine concerning electricity and its relation to animal economy is best acquired by the laboratory method. By that method of instruction each principle is impressed upon the mind through several separate paths of the sense perception and a manual dexterity is acquired which is essential to success in therapeutic applications.

This has been the plan adopted for teaching electrotherapeutics at the University of Michigan. Every form

of electric modality that has any distinctive physiological or therapeutic effect is studied in the laboratory as to its methods of generation, control and application to the patient. We believe this to be the only practical way for imparting the kind of instruction required for the practice of electro-therapeutics, but in our attempts to develop a naturally progressive and at the same time complete and consistent course of laboratory instruction we have found it a thing of slow growth.

This laboratory manual is the final result of our various trials and experiences and while we do not claim for it either perfection in the arrangement of matter or completeness in detail, we feel that the time has come for putting our plan in a form that will permit for it a wider usefulness as well as gain for it the intelligent criticism of the experienced workers in the field which it seeks to cultivate.

We take this opportunity to make grateful acknowledgement to Dr. Henry S. Carhart, Professor of Physics in the University of Michigan, for generous assistance we have received from him from time to time in the loan of scientific instruments and in the free use of information gathered from his thorough and comprehensive work on "Primary Batteries," and to Dr. Jeanne C. Solis for her valuable aid in reading proof and preparing our manuscript for the press.

THE AUTHORS.



## ERRATA.

Page 23 line 26 for " $\frac{1484}{1000}$ " read  $\frac{1000}{1484}$ .

" 26 " 2 omit "or"

" 26 " 13 for " $C = \frac{m E}{\frac{mr}{n} + \frac{R}{n}}$ " write  $C = \frac{m E}{\frac{mr}{n} + R}$

" 26 " 18 for " $\frac{m n}{n} = R.$ " write  $\frac{m r}{n} = R.$

" 43 " 26 for "experiment" write experimental.

" 50 problem 27 insert  $R = 2000$ .

" 72 line 4 for "floating" write placing.

" 97 " 26 for "110 direct" write 110 volt direct.

" 102 " 4 for "wire" write iron.

" 105 " 13 for "arrangements" write arrangement.

" 126 " 23 for "from the" write from or.

## MEASUREMENT OF THE DIRECT CURRENT.

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**The Laboratory Milliamperemeter.**—The ability to understand the working principles and to use intelligently some form of galvanometer is absolutely essential to the student of current electricity. A very simple instrument in the hands of a skillful operator can be made to

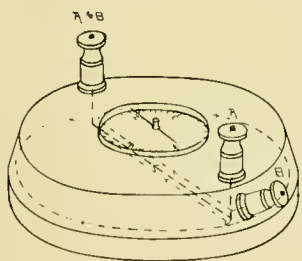


Fig 1.

yield comparatively accurate results. The instrument used in this laboratory (Fig. 1) is adapted by construction to carry currents which are best expressed, as thousandths of an ampere or “milliamperes;” such an instrument is called a milliamperemeter. This laboratory milliam-

peremeter consists of an ordinary compass needle mounted in a block of wood with the wire coils beneath the needle.

The coils are wound in form like the figure 8, the part between the binding posts being straight and the return, which is a semi-circle is made first on one side and then on the other. When the instrument is properly placed the the straight part of the coil lies below and parallel to the magnetic needle. When the “A” terminals are employed the current passes eight times below the needle, with the “B” terminals it passes forty times below it.

The fundamental phenomenon upon which the construction of this galvanometer form of milliamperemeter depends is as follows;

*A freely suspended magnetic needle tends to place itself at right angles to a wire through which a current of electricity is flowing.*

This instrument may be used:

- 1st, To detect the presence of a current;
- 2d, To determine the direction of a current;
- 3d, To determine strength of current;
- 4th, To measure electric resistances;
- 5th, To measure and compare electro-motive forces, etc.

This is a modified tangent galvanometer and for deflections not exceeding  $10^{\circ}$  or  $15^{\circ}$  the currents are nearly proportional to the deflection. The calibration of one of these instruments gave the following table which shows the current strength in milliamperes corresponding to a given deflection both for the A and B terminals. This table may be used for all instruments of this particular construction, but better results in practical work are obtained if a calibration table is prepared for each instrument. Each galvanometer should be carefully examined to see whether the needle swings freely. If this is the case it will come to rest in exactly the same position after every deflection if the instrument has not been moved.

Throughout the following experiments in which electric currents are to be measured, or compared, it will be necessary to so regulate the battery power as to keep the deflection within the limits for which the instrument is calibrated.

GALVANOMETER CALIBRATION TABLE.

DEGREES.	CURRENT IN MILLIAMPERES.		DEGREES.	CURRENT IN MA.		DEGREES.	CURRENT IN MA.	
	A Term.	B Term.		A Term.	B Term.		A Term.	B Term.
1°	1.5	.25	11°	21.2	5.65	21°	55.9	14.94
2°	3.	.52	12°	23.8	6.48	22°	61.	15.95
3°	4.5	.9	13°	26.5	7.3	23°	67.	16.97
4°	6.3	1.32	14°	29.5	8.2	24°	73.1	18.
5°	8.	1.8	15°	32.6	9.08	25°	79.3	
6°	10.	2.3	16°	35.8	10	26°	86.2	
7°	12.1	2.9	17°	39.1	10.9	27°	94.	
8°	14.3	3.54	18°	42.7	11.91	28°	102.2	
9°	16.4	4.2	19°	46.8	12.93	29°	110.8	
10°	18.7	4.9	20°	51.2	13.93	30°	120.0	

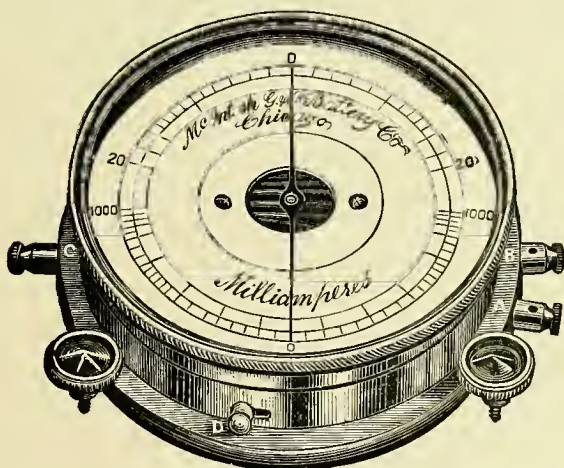


Fig. 2. The Ordinary form of Milliamperemeter.

## EXPERIMENTS WITH CURRENT STRENGTH.

**The Voltaic or Galvanic Cell** (T. 168)—A common and convenient method for generating a current of electricity is to make use of a glass or porcelain cup, containing a liquid, as acidulated water, in which two pieces of dissimilar metals are partially immersed. If to the upper extremities of these strips of metal, wires are attached and the opposite ends of the wires are connected to the binding posts of a galvanometer, the deflection of the galvanometer needle will give evidence that a current of electricity is flowing along the wires. The origin of the electricity in this case is due to the chemical action that is taking place between the acidulated water and one of the metal strips, and is at the expense of that metal since it is gradually consumed. This is a transformation of chemical energy into electrical energy. The cup and contained liquid and metals is called a **voltaic or galvanic cell**.

EXPERIMENT 1.—Take the small strips of copper and zinc furnished. Attach about two feet of copper wire to each strip and attach the other ends of the wires to the

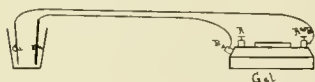


Fig. 3.

terminals of the galvanometer marked B in fig. 3. The most sensitive coil of the galvanometer is attached to the

B terminals, and for this reason they should always be used in measuring or testing for the presence of weak currents. *Place the galvanometer so that its needle shall point to zero and swing clear of the dial.* Immerse the strips in a glass of distilled water, *being careful that the strips do not touch,* and notice whether the galvanometer needle is deflected.

If it is, it indicates that a current of electricity has been generated and that there is a difference of electric potential between the copper and zinc.

EXPERIMENT 2.—Using different metals and a glass of hydrant water make the following combination, and test as in the preceding experiment. Note the deflection given in each case and determine which combination gives the greatest deflection, in other words the strongest current. The connections must be bright, the wires tightly fastened and the metal strips must be kept the same distance apart throughout the experiment. It will be found convenient to prepare a strip-holder from a small block of wood and pieces of brass, that are provided, to facilitate the fastenings of the plates and wires. Tabulate the results obtained as follows:

<i>Solution used.</i> .....	<i>Terminals.</i> .....
Zn—Cu .....Def.	Cu—C .....Def.
“—C ..... “	“—Sn..... “
“—Sn ..... “	“—Fe ..... “
“—Fe ..... “	“—Pb ..... “
“—Pb ..... “	“—Brass ..... “
“—Brass ..... “	“—Gal. Fe. .... “
“—Gal. Fe ..... “	

EXPERIMENT 3.—Repeat the preceding experiment using dilute sulphuric acid ( $H_2SO_4$ ) (1:20) and common salt (NaCl) solution as exciting liquids. Use the A terminals of the galvanometer and put a resistance of from 10 to 25 ohms\* in circuit. Make at least ten more combinations than are indicated in EXP. 2, and in each case take three readings.

1. First swing of the needle.
2. The permanent deflection.
3. The permanent deflection after three minutes.

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\* These resistances will be found on the side-table.

Note in each case which metal is electropositive (+) and carefully arrange the results in a series in the order of the greatest *first swing* of the galvanometer needle. The order of the metals in the zinc series and copper series should correspond. It will be found convenient always to attach the zinc to the north and copper to the south terminal of the galvanometer. In the properly arranged series each metal, beginning with zinc, will be electropositive (+) with respect to the one next below it.

EXPERIMENT 4.—Into some dilute sulphuric acid ( $\text{H}_2\text{SO}_4$ ) (1 : 20) place a strip of commercial zinc (Zn) and notice the result. Collect some of the gas given off in a test tube and determine what it is. What would you observe if you were to prepare the dilute acid? After the liquid has become clear replace the commercial zinc by a piece of chemically pure zinc and note the result (T. 172). The pure zinc should be carefully polished with sand paper to remove all traces of foreign metals and oxidation on its surface.

EXPERIMENT 5.—Amalgamate (see page 21) the commercial zinc (Zn) (T. 174). Notice its physical changes and try to bend it at one corner. Immerse it again in the acidulated water and compare the results with those in EXP. 4.

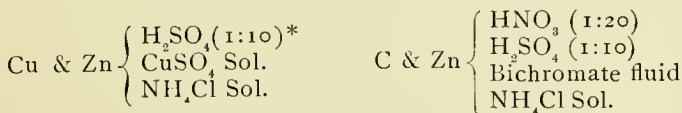
EXPERIMENT 6. Place a strip of copper in the dilute acid and notice if there is chemical action as in the case of the zinc.

EXPERIMENT 7.—Place the amalgamated zinc and copper strips in dilute acid, being careful that they do not touch each other. How do the results compare with those in EXP's 5 and 6 (T. 173, 174)?

EXPERIMENT 8.—Allow the metals to come in contact beneath the surface of the liquid. From which plate does

the gas arise? Is it the same as in EXP. 4? Connect the ends projecting above the liquid by a wire. Notice that the result is the same as before. Now break the connection, what does the result indicate? With the wires connected as before what would be the effect of putting a glass partition in the retaining vessel between the two plates?

EXPERIMENT 9.—Connect the wires to the A terminals of the galvanometer and put in circuit from 10 to 20 ohms resistance. When the needle rests at zero immerse the plates in the fluid and take the reading. Allow the current to flow 5 minutes and note the deflection every half minute. In this way determine what combination of metals and fluid gives the *strongest* and most *uniform* current. Make the following and a few other combinations:



Pb and Zn with  $\text{H}_2\text{SO}_4$  (1:10) and others.

EXPERIMENT 10.—Take two dissimilar metals, place one above the tongue and the other beneath it and then bring the ends in contact. Observe the peculiar sensation. Try several combinations, noticing what relation the intensity of sensation bears to the deflection of the galvanometer needle obtained with the same pairs of metals. What does this experiment demonstrate?

The tongue test is a convenient method for detecting weak currents and for currents of short duration. By practice the experimenter can approximately estimate electro-motive forces as high as 10 volts without danger or discomfort. The student should also familiarize himself

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\*These solutions will be found on the side table. Fill the glass to the depth of 2 inches in each case.

with the difference in sensation caused by the positive (+) and negative (—) terminals and thus be able to determine by this means the direction in which a current is flowing along a given wire.

EXPERIMENT 11.—Place a tumbler containing fresh bichromate solution  $\frac{1}{4}$  inch deep over your galvanometer dial. In this, place a narrow strip of amalgamated zinc over the north-seeking end of the needle and a carbon plate over the south-seeking end. Touch the upper ends of the strips together and observe the needle. It may be necessary to use a thin glass beaker and to alternately open and close the circuit to get a noticeable effect. What relation does this experiment bear to the preceding? What do the two experiments prove concerning a battery?

EXPERIMENT 12.—**The Volta Pile.**—Construct a Volta pile (T. 164) using 11 plates each of copper and zinc separated by squares of blotting paper moistened

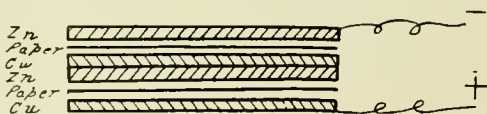


Fig. 4.

with a dilute acetic acid solution. (Strong NaCl solution or any weak acid solution would answer). The squares of paper should be just the size of the plates and should be moistened before setting up the pile. Arrange the plates in the order indicated by the diagram (Fig. 4), soldering wires to the terminal plates and fastening the whole together with a rubber band. With the least possible delay have its voltage measured on the voltmeter, being careful that you have made the proper connection before closing the circuit

through the instrument. Bring the wires into contact with your tongue and compare the sensation with that you experience in EXP. 10. Attach the wires to the A terminals of the galvanometer with a resistance the same as you used in the Zn, Cu and NaCl combination and compare results.

The **volta pile**, in some form, has been called upon to do duty in the construction of that innumerable variety of "body batteries" which are sold under the names of "Electric Belts," "Electric Plasters," "Electric Shoe Soles," etc., when there is any pretence in these objectionable devices to generate any current whatever, for often the word "electric" is simply employed as a catch-penny name and has no other reason for its application to the thing so named.

Many of the electric belts and other such appliances are capable of generating a current of considerable strength so that when used by those ignorant of the action of electricity or of the proper treatment of disease by it, they seldom do good and often do great harm.

**Soldering.**—A soldering fluid is prepared by dissolving scraps of zinc in hydrochloric acid (HCl) till no more zinc is dissolved. The parts to be united must be scraped clean and bright, and care must be taken to keep them so. Now apply some of the soldering fluid to the surface of the metals, place a *small* piece of solder between them and apply heat either with a soldering iron or by holding the parts in the flame of a Bunsen burner, being careful to remove them as soon as the solder is melted, and keep them in position till it cools. Should the solder not spread out and adhere intimately to all the parts the process should be repeated.

## BATTERY POLARIZATION.

(T. 175, 176.)

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Construct a Volta cell (T. 166), using plates  $1\frac{1}{2} \times 3$  inches. Use the same plate holder that you used in EXP. 2, being careful that the metallic parts do not touch and thus "short circuit" the cell. Amalgamate only the the lower three-fourths of the zinc to prevent its breaking, and be sure that all *metallic connections* are *bright* and *tight*.

EXPERIMENT 13.—Connect the terminals of your cell to the A terminals of the galvanometer, having in circuit a resistance of at least 10 ohms. When the needle comes to rest immerse the elements in the dilute acid. Notice that the angle of deflection diminishes rapidly for a time and then more slowly. Allow the cell to continue in action for ten minutes and then jar or brush the gas from the upper plate, noticing the effect on the needle. Repeat, keeping the plates constantly in motion. In each case take the galvanometer reading every half minute and *tabulate the results*.

EXPERIMENT 14.—Replace the dilute acid of EXP. 13 by bichromate solution ( $K_2Cr_2O_7 + H_2SO_4 + H_2O$ ). Allow the cell to continue in action ten minutes and then compare the deflections of the needle with those of the preceding experiment.

EXPERIMENT 15.—Again replace the bichromate solution of EXP. 14 by a solution of copper sulphate ( $CuSO_4$ ). Allow the cell to act ten minutes, take half-minute readings and compare them with those of EXP'S 13 and 14.

EXPERIMENT 16.—Attach the terminals of Volta's pile to the A terminals of the galvanometer and let the time, resistance and observation be the same as in the preceding experiments. Do the deflections vary? Why?

*The Volta's pile should be taken apart and the plates cleaned and dried as soon as possible after using it to avoid corrosion of the plates.*

EXPERIMENT 17.—Examine the Daniell's cell\* on the side-table. Test it as to its polarization in the same way as you did the cells in the preceding experiments. (T. 181).

EXPERIMENT 18.—Test Bunsen's cell\* as you did the Daniell's and examine the Grove's cell. (T. 182, 183).

EXPERIMENT 19.—Determine the constancy of the Leclanché cell, having it connected up for ten minutes. Record the readings every half minute. Now allow the cell to stand on open circuit for a minute and then close the circuit only long enough to take the reading the instant the needle stops oscillating. Continue this for ten minutes keeping the circuit closed as short a time as possible. Do the results indicate a recovery in the strength of current? If so, to what is it due? (T. 184). Because of the time required for the needle to come to rest it will be quite as instructive to compare the first swings of the needle in the later part of this experiment.

It is found that the current from the voltaic cell rapidly diminishes in intensity, so that in a short time the activity of the cell is very much reduced or may cease altogether. This may be due to several causes, the chief of which is the collection of hydrogen on the copper plate, thus causing the **polarization** of the cell.

From Ohm's law (see page 22), it is apparent that any-

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\* Note, Specimens of these cells will be found on the side table.

thing which tends either to diminish the E. M. F. or to increase the resistance of a cell must cause a diminution of the current strength. The chief effects of polarization are the following,—

1. The presence of hydrogen bubbles on the copper plate sets up an E. M. F. in an opposite direction to the E. M. F. acting from the zinc to the copper plate. The effective E. M. F. is then equal to the difference between the two.

2. The effective surface of the copper plate is decreased by the highly resistant hydrogen gas, and then the internal resistance of the cell is increased and the current is correspondingly decreased.

**Methods of Preventing Polarization.**—1. Any mechanical method of removing the hydrogen from the negative plate such as brushing the plate or keeping the liquid of the cell agitated would diminish polarization. This method has never proved to be very satisfactory and is now obsolete.

2. Polarization may be prevented by surrounding the negative plate of the cell by some oxidizing material which is capable of forming a chemical combination with the nascent hydrogen. In this manner the two chief causes of polarization are prevented. Nitric acid ( $\text{HNO}_3$ ), chromic acid ( $\text{CrO}_3$ ), manganese dioxide ( $\text{MnO}_2$ ) and Calcium hypochlorite ( $\text{Ca}(\text{ClO})_2$ ) are commonly employed.

3. By placing the negative plate in some salt whose metallic element can easily be replaced by nascent hydrogen, polarization can be entirely prevented. The chemistry of the Daniell and Chloride of Silver cells will illustrate this principle.

## THE ELECTRIC BATTERY.

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An electric battery is composed of one or more cells, each cell consisting of any two dissimilar metals placed in a liquid capable of chemically attacking either of them. Any combination of such simple cells or elements is called a battery. A battery composed of cells is still one of the principal sources of electricity as it is used by Physicians. One of the simplest forms of cells for such a battery consists of a zinc and a copper plate with a dilute solution of sulphuric acid for exciting liquid and is known as the **simple voltaic cell**.

The **generating plate** is the name given the zinc or other metal attacked by the liquid because part at least of the chemical energy expended is utilized in the generation of an electric current. This is also known as the positive (+) plate and it invariably diminishes in size and weight during the action of the cell

The **collecting plate** is the term applied to the copper, carbon, platinum or other metal used with the zinc. This is also called the negative (—) plate and it should not be acted upon by the liquid in which it is immersed.

The **elements** consist of one generating and one collecting plate. It is essential that the exciting liquid should have a greater chemical affinity for the former than for the latter.

The **poles** are the copper strip, from which the current starts in the external circuit, and the zinc strip toward which the current flows. These are known as the *positive* (+) and *negative* (—) poles or *terminals* respectively.

The **circuit** constitutes the entire path of the current. It consists of an *internal* part made up of plates and liquid of the cell and an *external* part composed of the connecting wires and any intervening body with which they may be in contact.

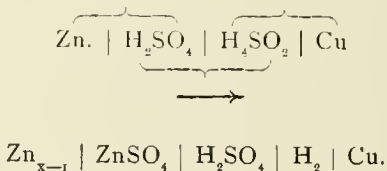
A cell is on **short circuit** when its terminals are connected by a short wire of no appreciable resistance.

A cell is on **open circuit** when its terminals are not connected by a conductor or when the external resistance is infinitely great.

## THE CHEMICAL REACTION IN VARIOUS BATTERIES.

**The Simple Voltaic Cell.**—This cell is composed of a strip of zinc and one of copper immersed in a dilute solution of sulphuric acid (1:20 by vol.). During the action of the cell the zinc is attacked by the acid, but the hydrogen gas thus liberated is transferred by a series of molecular interchanges to the copper strip where it can first be seen.

If we represent the arrangement of the metals in the liquid as follows:



The arrow represents the direction of the current through the cell. The zinc and the hydrogen are displaced in the direction of the current, while the sulphurion

or  $\text{SO}_4$  part of the acid, is displaced in the other direction. All metals and hydrogen are electro positive, and travel in an electrolyte with the positive current. Zinc sulphate is formed at the expense of zinc and sulphuric acid, and hydrogen is set free at the copper plate. The simple chemical action taking place is the displacement of the hydrogen of the acid by zinc, forming zinc sulphate instead of hydrogen sulphate.

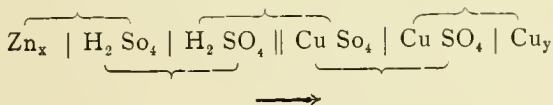
The electro-motive force (E. M. F.) of this cell is about 1 volt and this is reduced to  $\frac{1}{2}$  volt upon polarization.

**The Daniell Cell.**—This cell most commonly consists of a glass vessel containing a clear solution of copper sulphate, in which is placed a cylinder of sheet copper which serves as the negative plate.

Within the copper cylinder is placed a porous cup of unglazed earthen ware, which contains the zinc rod immersed in dilute sulphuric acid or preferably a dilute solution (5%) of zinc sulphate.

**The Gravity Cell.**—Is a modified form of the Daniell, in which the two liquids are separated only by their difference in density.

If we represent the arrangement of metal plates as follows:



then after the first interchange it becomes

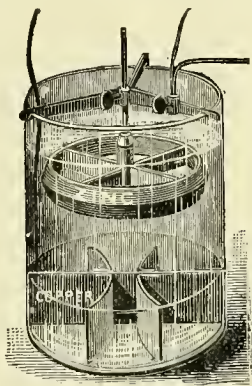
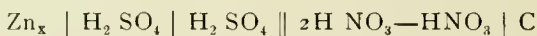


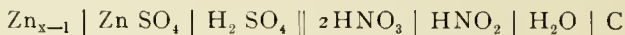
Fig. 5. Gravity Cell.

It will be seen that all metallic elements and hydrogen have been displaced in the direction of the current. The zinc has lost one atom while the copper has gained one. One molecule of zinc sulphate has been formed and one of copper sulphate has disappeared. The hydrogen displaces the copper in  $\text{Cu SO}_4$  and never reaches the copper plate. Polarization is entirely prevented and the cell is one of the most constant known. The E. M. F. is 1.08 volts.

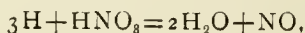
**The Bunsen Cell.**—This, like the Daniell, is a two fluid cell. The zinc plate bent in the form of a cylinder, is generally immersed in dilute sulphuric acid contained in a glass vessel. A cup of unglazed earthenware is placed within the zinc cylinder and contains a bar of carbon immersed in strong nitric acid. The hydrogen formed at the zinc plate traverses the porous cup, but then decomposes the nitric acid with the formation of a corresponding amount of water. The electric chain may be represented as follows:



After the first step in the chemical reaction this becomes—



It will be seen that the nitric acid has been reduced to nitrous acid ( $\text{HNO}_2$ ), which in turn may lose an atom of oxygen, becoming hypo-nitrous acid ( $\text{HNO}$ ). Or further, the nitric acid may be broken up completely, according to the following reaction:—



The nitric oxide gas (NO) thus formed on escaping from the liquid immediately combines with oxygen of the air, forming the red and very corrosive fumes of nitrogen peroxide ( $\text{NO}_2$ ). This cell is capable of furnishing a very strong current, but the generation of corrosive fumes and the fact that it requires attention at frequent intervals cause it to be much less used than other forms of cells. The E. M. F. is 1.8 volts.

**The Bichromate Cell.**—The elements in this cell are zinc and carbon plates immersed in a fluid composed of bichromate of potassium, (or chromic acid), sulphuric acid and water.

When a solution of potassium bichromate is treated with sulphuric acid, a purely chemical reaction takes place, resulting in the formation of chromic acid. Thus:—

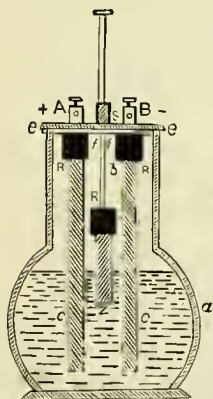
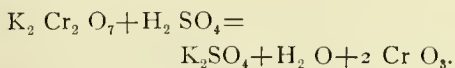
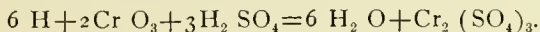


Fig. 6. Bichromate Cell.

The chromic acid,  $\text{CrO}_3$ , is the useful agent to effect depolarization by the oxidation of hydrogen. The process is supposed to be represented in the following reaction:—



The final result is, therefore, the production of the sulphate of zinc (at the positive plate), the sulphates of potassium and chromium, and water.

The cell should be so constructed that both the zinc and carbon plates can be removed from the liquid when not in use. The E. M. F. is two volts.

**Battery Fluid.**—The following formulæ are generally employed in the preparation of the battery fluid:

No. 1.	Sulphuric acid (commercial).....	3 fluid oz.
	Potassium bichromate (powdered).....	2 oz.
	Water .....	16 fluid oz.
	*(Bisulphate of mercury.....	2 drachms.

First dissolve the bisulphate of mercury and then the potassium bichromate in the water, and then slowly add the sulphuric acid with constant stirring. Allow the liquid to cool before using.

No. 2.	Chromic acid ( $\text{Cr O}_3$ ).....	2 oz.
	Water .....	16 fluid oz.
	Sulphuric acid.....	$1\frac{1}{3}$ “ “
	(Bisulphate of mercury.....	2 drachms.)

This fluid is much to be preferred to the former, since the absence of potassium salts prevents the formation of chrome alum,  $\text{K}_2\text{Cr}_2(\text{SO}_4)_4$ , which is very difficult of removal from the bottom of the battery jar.

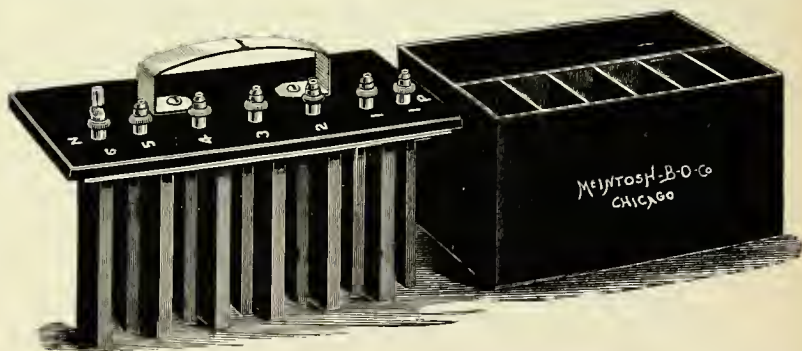


Fig. 7. A Series of Bichromate Cells.

**The Leclanche' Cell.**—This form of cell is probably more used by physicians than all other forms taken

□ \*NOTE.—The bisulphate of mercury must never be placed in the battery fluid, except when carbon is used as the negative plate.

collectively. The little attention required, the ease with



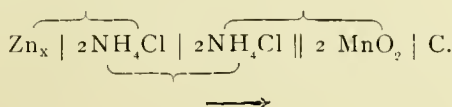
Fig. 8. Lelanché Cell.

which it can be restored and the cheapness are all factors which have brought it into such general use. The elements are zinc and carbon and the exciting liquid is a strong solution of ammonium chloride. Depolarizers

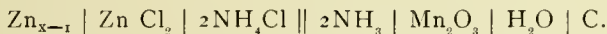


Fig. 9. Carbon plate with depolarizer.

are sometimes employed. When manganese dioxide ( $\text{MnO}_2$ ) is used as a depolarizer it is packed about the carbon plate and the arrangement may be represented as follows:



which becomes



As a result of evaporation the double chloride of zinc and ammonium is liable to crystallize on the zinc and on the bottom of the glass jar. This should be prevented as far as possible since it produces a deleterious effect. Owing to oxidation and local action the zinc rod is often entirely severed at the surface of the liquid. This is one of the first signs of disorder in the cell and can be almost indefinitely postponed by protecting the zinc where it passes through the surface of the liquid by a thin coat of paraffine. This cell is well adapted to open circuit work. Its E. M.

F. varies from 1.4 to 1.7 volts, but in a short time polarization may reduce it to .7 volt from which it slowly recovers. The tops of the battery jar and the carbon plate are placed in melted paraffine and if on setting up the cell, these parts are not moistened by the battery fluid, disagreeable "creeping" of the salts will be prevented.

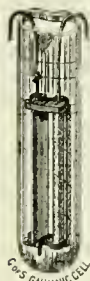


Fig. 10.

**The Chloride of Silver Cell.**—The elements in this cell are zinc and silver and on the latter is fused the silver chloride which is readily reduced by nascent hydrogen and thus serves as a depolarizer. The exciting liquid may be ammonium chloride and in this case the chemical reaction may be represented as follows:



After the first interchange this becomes



Polarization is prevented in a manner analogous to that in the Daniell cell. Because of its small size this cell adapts itself admirably to the construction of *portable* batteries for physicians use. It should never be used to send anything but small currents as the materials would otherwise quickly become exhausted. The E. M. F. is about 1.1 volts.

#### NOTES ON THE ACTION OF BATTERIES.

1. In all cells in which acid is used as the exciting liquid the zinc must be amalgamated. In other types of cells amalgamation of the zinc is not accompanied by any deleterious effects.

2. During the action of a cell no effervescence of gas should occur at the zinc plate. Such phenomena

indicate that the zinc should be more thoroughly amalgamated.

3. In batteries employing porous cups the fluid about the incorrodable plate should never be higher (nor in fact quite as high) as the fluid about the zincs. This will diminish one form of local action by delaying the diffusion of the oxidizing fluid toward the zinc plates.

4. Most batteries should have their plates removed from the liquid immediately after they have been used. In two fluid cells the liquids should also be put in their respective labeled bottles.

5. Detached carbon plates can be resoldered to their attachments after a thin layer of copper has been deposited upon one end by electrolysis. (This process will be more fully treated under the subject of electrolysis).

#### METHODS OF AMALGAMATING ZINC.

Any expenditure of chemical energy within a cell which does not contribute to the production of an electric current is designated as *local action*. Such action may take place either upon closed circuit or upon open circuit. Such wasteful chemical actions are most often due to the local electric circuits formed between commercial zinc and its impurities. It is almost entirely prevented if the surface of the zinc is covered by an alloy of mercury and zinc, which is known as an amalgam.

The zinc plate may be amalgamated in the following ways:

1. *Clean* the zinc in dilute acid and rub mercury over its surface with a small cloth. The mercury spreads readily if the zinc surface is properly cleaned.

2. An amalgamating fluid is prepared by dissolving mercury in aqua regia (three parts of hydrochloric acid to

one of nitric acid) and then adding a small excess of hydrochloric acid. If zinc be dipped into this solution for a few moments its surfaces will receive a deposit of metallic mercury.

3. A soluble salt of mercury is sometimes dissolved in the battery fluid to keep the zinc amalgamated.

4. An alloy of zinc and mercury is sometimes prepared for the positive plate. Such plates seldom need be removed for amalgamating, but since they are much more brittle greater care must be exercised in handling them.

NOTE.—All forms of jewelry, such as rings, chains, etc., are liable to injury by amalgamation and should consequently be removed before working with mercury.

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## OHM'S LAW AND THE ELECTRIC UNITS.

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In order to understand this most important law of voltaic electricity it is first necessary to sharply distinguish between the three following electrical quantities:

1. The **Current** (C) is the quantity of electricity which flows past any point in a circuit in one second. The unit of current strength is called the **Ampere**.

2. **Electro-motive force** (E. M. F.) or (E) may be defined as that which causes electricity to move from one point to another. It is sometimes spoken of as electric pressure. The unit of electro-motive force is called the **Volt**.

3. **Resistance** (R) refers to that which impedes or checks the flow of electricity over a conductor. It is the inverse of conductance. The *unit* of resistance is called the **Ohm**.

Ohm's law may be expressed as follows: *The current which flows in a circuit varies directly as the electro-motive force, and inversely as the resistance.*

This relation may be expressed as

$$C = \frac{E}{R}$$

when C, E and R represent respectively the units of current, electro-motive force and resistance. From the above relation it is evident that  $E = CR$  and  $R = \frac{E}{C}$ .

It follows that if any two of the three quantities be given the third can be derived by calculation.

[The following are among the units adopted by the Electrical Congress held in Chicago in 1893. They are designated **International Units** to distinguish them from definitions previously adopted.

The *International Ohm* is represented by the resistance offered to an unvarying electric current by a column of pure mercury at the temperature of melting ice, 14.4521 grammes in mass, of a constant cross-sectional area and of the length of 106.3 centimeters.

The *International Ampere* is represented by the unvarying electric current which deposits silver from a solution of silver nitrate in water at the rate of .001118 grammes per second. The solution must be of a definite strength, and the whole process must be according to certain specifications.

The *International Volt* is that electromotive force which, acting through a resistance of one ohm, will produce a current of one ampere. It is represented sufficiently well by  $\frac{1}{1000}$  of the electromotive force of a Clark's standard cell at 15° C. ]

## METHODS OF JOINING CELLS.

**A. In Series.**—In this method the cells are connected so that the positive pole of one joins the negative of the next and so on throughout the entire number of cells.



Fig. 11.

**B. In Multiple Arc.**—In this arrangement the cells are so joined that the positive poles are all connected together to form a common positive pole on one side, the negative poles being also joined together to form a common negative pole on the other side (T. 168).



Fig. 12.

**C. In Combination.**—Partly in series and partly in multiple arc. In this arrangement groups of cells connected in series are there joined in multiple arc as if each group were a single cell.

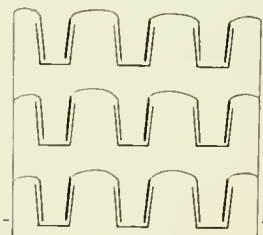


Fig. 13.

The group in the diagram would be spoken of as three in series and three in multiple arc, involving nine cells, while five in series and eight in multiple arc would require forty cells, etc.

### OHM'S LAW APPLIED TO CELLS IN SERIES.

Ohm's law being expressed by  $C = \frac{E}{R}$  is true only when  $R$  represents the sum of all the resistances in circuit

and when  $E$  represents the algebraic sum of all the electro-motive force. If  $E$  = the E. M. F. of a cell and  $r$  = its internal resistance, then the current sent through a given external resistance ( $R$ ) will be represented by

$$C = \frac{E}{R + r}$$

If  $m$  represents any number of cells joined in series it follows, since both  $E$  and  $r$  increase with  $m$ , that the current will be represented by  $C = \frac{mE}{mr + R}$ .

When the external resistance or ( $R$ ) = 0 or when it is so small as to be negligible  $C = \frac{mE}{mr + 0} = \frac{E}{r}$  it is evident that  $m$  cells furnish no stronger current than one alone. When on the other hand  $R$  is a large quantity as compared to  $mr$ ,  $C = \frac{mE}{R}$  and the current is therefore  $m$  times as great as that from one cell.

#### OHM'S LAW APPLIED TO CELLS IN MULTIPLE.

When  $r$  equals the resistance of a single cell and we have  $n$  such cells joined in parallel, the total resistance becomes  $\frac{r}{n}$ . The E. M. F. of  $n$  cells in multiple is no greater than for a single cell, Ohm's law therefore becomes

$$C = \frac{E}{\frac{r}{n} + R} = \frac{nE}{r + nR}$$

It follows that when the external resistance or ( $R$ ) = 0 the current is  $n$  times as great as for a single cell, since  $C = \frac{nE}{r}$ .

When, however,  $R$  is a large quantity the formula is approximately true or when written  $C = \frac{n E}{n R}$  in which case  $n$  cells furnish no stronger current than a single cell.

#### OHM'S LAW APPLIED TO A MIXED CIRCUIT.

(A combination of cells in series and multiple arc.) Fig. 12.

If  $m$  is the number of cells in series and  $n$  the number in multiple arc then the whole number of cells  $= m n$ . From preceding articles it follows that the resistance of  $m$  cells in series  $= m r$  and if in  $n$  such groups be joined in multiple arc the entire internal resistance will become  $\frac{m r}{n}$ . Since the E. M. F. is only affected by the number of cells in series, Ohm's law becomes:

$$C = \frac{m E}{\frac{m r}{n} + \frac{R}{m}} = \frac{E}{\frac{r}{n} + \frac{R}{m}}$$

From this formula the following rule can be mathematically derived, viz. *A given battery will send the greatest current through an external resistance when it is so connected that the internal and external resistance are equal.* Or when  $\frac{m n}{n} = R$ .

## CONSTRUCTION OF EXPERIMENTAL BATTERY.

An eight cell battery is now to be constructed from the materials furnished. The wooden frame for holding the battery jars and plates is furnished and should be fitted up with the plates, wires, binding-posts, a device for raising and lowering the plates, etc. Contact is made with the zinc plates by soldering bare copper wires 8 c.m. in length to them. Similar wires are to be soldered to eight pieces of sheet copper 1 by 1.5 c.m. which can be wedged in contact with the carbon plates thus making the contact with them. For a more permanent form of battery it would be advisable to deposit first a thin layer of copper upon one end of each of the carbon plates by electrolysis and then solder directly to the carbon plate. In order that the battery when joined in series may yield the required E. M. F., (16 volts), all contacts must be *clean* and *tight*, and all local action prevented by thorough amalgamation of the zinc plates.

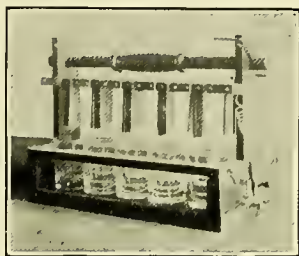


Fig. 14. Experimental Battery.

### EXPERIMENTS WITH THE BATTERY.

EXPERIMENT 20.—The galvanometer may be used to determine the polarity of wires coming from a battery or other generator of an electric current, thus indicating the direction of the current (T. 197). Connect the terminals of the Volta cell to the B terminals—the long coil of the

galvanometer—and notice the direction in which the needle is deflected. Now reverse the poles and observe that the deflection is in the opposite direction. After having once determined the deflection for a current of known direction, you can easily determine the polarity or direction of current in a wire when the generator is not visible. The importance of this matter cannot be well over-estimated, since in practice it is absolutely essential to know the direction of current when passed through the body.

EXPERIMENT 21.—Let the student opposite you arrange wires coming from a hidden cell that you may test the polarity with the galvanometer. Determine the polarity of the terminals marked X and Y, over the side-table which are in connection with a cell in the dispensing room. Note accurately the time when the test was made.

EXPERIMENT 22.—Pass the current from a cell by means of an insulated wire, directly over and parallel to the galvanometer needle. The wire can be wound around the A terminals to hold it in position. Now bend the wire leading from the cell to the galvanometer so that it also lies nearly parallel to the needles. Why does this affect the deflection? Bring a magnet or a piece of iron near the needle while the current is flowing and notice that the deflection is changed.

EXPERIMENT 23.—*The E. M. F. of a cell is independent of the size of the cell.* Prove by placing, in circuit with your galvanometer, a resistance of 200 ohms, using



Fig. 15.

the A terminals or a still larger resistance with the B terminals. The latter would be the better method in comparing the electro-motive forces of different cells. Prepare a little cell (Fig. 15) by hollowing out a piece of carbon so it will hold a drop of bichromate fluid, thus making

the carbon serve the double purpose of negative element and battery jar. The positive element should be a small pointed piece of zinc, which is to be dipped into the drop of liquid when the circuit is to be completed. Pass the current successively from a large bichromate cell,—one cell of your experimental battery—and the small cell just prepared, through the galvanometer. Do you get the same deflection in each of the these cases? What do the results indicate?

EXPERIMENT 24.—With the galvanometer and resistance as in the previous experiment, connect one cell of the experimental battery with a large bichromate cell so that the current from one shall oppose that of the other. Finally join the large cell in opposition to the little cell of EXP. 23. In both cases observe the needle and account for the results.

EXPERIMENT 25.—Without changing the galvanometer or resistance, connect one of the bichromate with a voltaic cell so that their currents shall tend to oppose. Why does the galvanometer needle move in this case and not in the other? What is the logical conclusion, and what is the direction of the current in this experiment?

EXPERIMENT 26.—*The E. M. F. is independent of the depth of fluid in the cell.* Prove by leaving in circuit your galvanometer and a resistance of at least 200 ohms, take the galvanometer reading and then gradually raise the plates from the liquid. Observe that the deflection does not change until the plates leave the liquid. Why do you use a high resistance in this experiment?

EXPERIMENT 27.—*The E. M. F. of a number of cells, in series, is equal to the sum of the electro-motive forces of the several cells.* Prove by putting in circuit with your galvanometer, A terminals, a resistance of 200 ohms and then pass the current from first one cell then two, three,

etc., till the entire eight of the experimental battery are in circuit. Take the galvanometer reading as each cell is introduced and tabulate results, writing the current strength opposite each deflection. Can you explain the results? (T. 212, fig. 121).

EXPERIMENT 28.—*The E. M. F. of a number of cells in multiple arc is the same as that of one cell.* Prove this by having the galvanometer and resistance as in the preceding experiment, placing first one cell in circuit then adding the remaining cells one at a time in multiple arc. Take the galvanometer reading at each addition and observe that the results throughout agree with the above statement. Do you think it necessary to have so much resistance in circuit?

EXPERIMENT 29.—*The E. M. F. of a battery composed of  $x$  cells in series and  $y$  cells in multiple arc (the number of cells being  $xy$ ) is equal to  $x$  times the E. M. F. of one cell.* Having galvanometer and resistance arranged as in the past experiments, prove by joining the cells in groups, of two in series then joining the groups, one at a time, in multiple arc, each time taking the galvanometer reading. It will not be found difficult to verify the above statement by the arrangement of the cells.

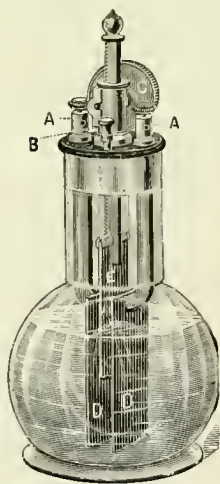


Fig. 16. Water Rheostat. between the electro-motive forces of the opposing groups. Having in circuit a resistance of 200 ohms and the galvanometer, A terminals, couple two cells

EXPERIMENT 30.—When groups of cells are coupled against each other the available E. M. F. is the difference

of the experimental battery in series, and take the reading. Now replace the two cells by the entire eight of the battery so joined that three of the cells shall oppose the other five. Does the needle indicate the same E. M. F. in both cases? Other combinations may be made to prove the statement.

EXPERIMENT 31.—No current of electricity can flow except in a closed circuit, and the current is of the same strength at all points in the circuit. Prove this by connecting the entire battery in series with four resistances varying from 10 to 600 ohms. Now introduce the galvanometer in the circuit between any two cells or resistances or between the battery and a resistance, and notice that the needle indicates the same current in each case.

EXPERIMENT 32.—Having one cell of the experimental battery send the current through the galvanometer and take the reading. Now introduce in succession the following resistances 25, 60, 100, 150, 200 and 600 ohms. In the last case use the B terminals also. In each case take the deflection and by reference to the calibration table find the strength of current. Also *calculate* the current in each case by Ohm's law, and compare results. The  $r$  of a cell may be called 4 ohms.

*What are the sources of error?*

EXPERIMENT 33.—Use the A terminals of the galvanometer to measure the current given by 1, 2, 3, 4 cells successively, coupling the cells in series. Why do 4 cells give no greater current than one? *Calculate*

the strength of current in each case. The resistance of the galvanometer coil connected with the A terminals is about one-tenth of an ohm.



Fig. 17. Graphite Rhostat.

EXPERIMENT 34.—Repeat EXP. 33, using a resistance of from 100 to 200 ohms. Why does the current increase as the cells are added? Calculate the current by Ohm's law as before.

EXPERIMENT 35.—Again repeat EXP. 33, but this time coupling the cells in multiple arc instead of in series. Why do you get a greater current from four cells than from one in this case? Again express the strength of current by Ohm's law.

EXPERIMENT 36.—With the A terminal of the galvanometer and a resistance of 200 ohms, measure in succession the current from 1, 2, 3 and 4 cells in multiple arc. Why do the four give no greater current than one?

To measure the internal resistance of a cell join two cells of the experimental battery in opposition and then send the current from a large bichromate cell through them, having the galvanometer in circuit. Note carefully the deflection of the galvanometer. Now remove the two cells joined in opposition and introduce in their place a known resistance such as will make the deflection exactly equal to the former reading. The current being the same in the two cases, it is evident that the resistance introduced equals that of the two cells of the experimental battery. This conclusion is only allowable in case the E. M. F.

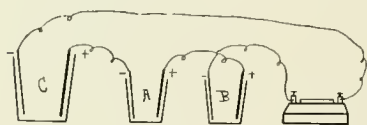


Fig. 18.

throughout the experiment is kept constant, and care must be taken that the E. M. F. of the cell does not fall

because of polarization. It is advisable to repeat this experiment, joining two other cells of the experimental battery in opposition and then average the results.

EXPERIMENT 37.—Having the experimental battery

joined in series, pass the current through a glass of distilled water, using the B terminals of the galvanometer. Now add enough salt to the water to make a 1 per cent. solution. *Calculate* the resistance of the water in both cases, letting the wires be immersed one inch and keeping them one inch apart. Two per cent. and other solutions may also be measured.

EXPERIMENT 38.—Using from four to eight cells of the experimental battery, determine by calculation from Ohm's law, **the resistance of the various parts of the body**, being careful in regions about the head and neck that the current is barely strong enough to give a good reading on the galvanometer. The electrodes should be carefully covered with absorbent cotton and moistened in a solution of common salt or ammonium chloride. *In no case should the metallic portion of an electrode be brought in contact with any part of the body except when local electrolytic effects are desired.*

Determine the resistance through the following:—

1. From one hand to the other;
2. From the hand to the elbow;
3. From elbow to the back of the neck;
4. Laterally through the neck;
5. From back of the neck to the temple;
6. Through the temples;
7. Through the hand;
8. Through the muscular part of the forearm.

Determine the difference in effect when large electrodes are used instead of small ones. (Difference in current density. See pg. 38.)

EXPERIMENT 39.—Measure the unknown resistance at 1, 2, 3, 4 and 5 on block A or B, C, D, E, F, etc., by calculation from Ohm's law, using, when possible, only

sufficient battery power to give a deflection not much exceeding  $10^\circ$ . For large resistance the B terminals will give the best results, but in this case the resistance of the galvanometer must be considered in the calculation.

EXPERIMENT 40.—Resistance may be measured by **substitution**. In this method the resistance to be measured is placed in circuit and the galvanometer reading taken. The unknown resistance is then removed from the circuit and in its place a known resistance is substituted which will give exactly the same deflection as did the unknown. The two resistances are then equal—

(1) in case you succeeded in getting exactly the same deflection in both cases, and

(2) *if the E. M. F. of the battery has not varied during the experiment.*

Measure the R of two blocks of “unknowns,” and report the results to the instructor in charge.

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### DIVIDED CIRCUITS (T. 409).

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If the poles of a battery be connected by two or more conducting paths, the current will divide, each path carrying a definite portion of the whole current. The principal laws relating to **divided circuits** and joint resistances are the following:

1. The sum of the currents in the several branches is equal to the main current.

2. Each branch will carry such a proportion of the whole current as its conductivity bears to the conductivities of all the branches. The **conductivity** of any path is the **reciprocal** of its resistance. If the resistance = R the conductivity =  $\frac{1}{R}$ .

3. The total conductivity of a number of branches of a divided circuit is equal to the sum of the conductivities of the several branches.

4. The joint resistance of any number of branches in divided circuit is less than the resistance offered by any branch taken separately.

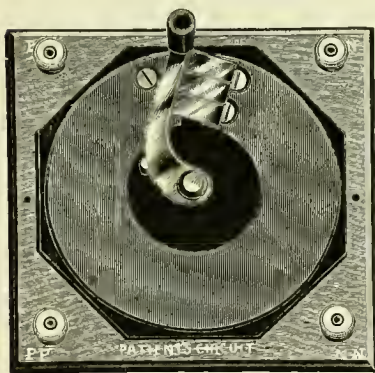


Fig. 19. Shunt Rheostat.

with three feet of German silver wire, number 30 to 36, and note the effect on the deflection. The wire is a "shunt" and forms one branch of a divided circuit. Now replace the German silver wire by a short piece of copper wire and notice that the deflection decreases still more. Why?

EXPERIMENT 42.—With the same terminals of the galvanometer, but using only one cell, connect the terminals by two wires which have a  $R$  of 25 and 100 ohms respectively. Now, introduce the galvanometer first into one circuit and

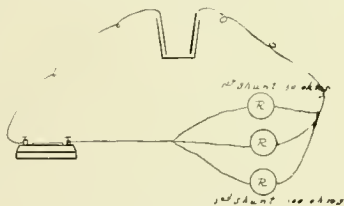


Fig. 20.

then the other and observe the deflections. From your results what *relation* can you deduce between the *current strength* and the *resistances* of the branches? Write out the ratio between the two currents.

EXPERIMENT 43.—Using but one cell, put in circuit your galvanometer and a  $R$  of 50 ohms. Take the reading. Now, in the same part of the circuit and between the galvanometer and battery, place a shunt having a  $R$  of 50 ohms. Take the reading and then introduce a second shunt having a  $R$  of 100 ohms beside the first. Notice as each resistance is introduced the needle indicates an increase of current. Why?

Take the reading in milliamperes and then remove the galvanometer from the position in the main circuit closing

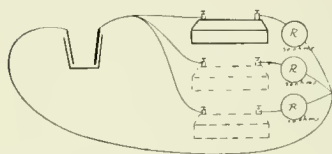


Fig. 21.

the circuit where it was removed. Place it in turn in each branch of the divided circuit, being careful to keep the circuit closed in all the branches. In each case re-

register the current in milliamperes. Determine whether the sum of the currents in the shunts equals that in the main wire. Make a complete diagram showing the position of each part in every case.

EXPERIMENT 44.—Use one of the boards arranged with a divided circuit. Place the galvanometer in the main circuit.

1. Determine by substitution each of the six resistances.
2. From the values obtained in one, calculate the joint resistance of the six.
3. Determine the joint resistance of the six by the substitution method.
4. From data thus far at hand calculate what per cent. of the whole current will flow in each branch.
5. Determine experimentally, using one or possibly two cells, the whole current flowing in the six part shunt.

6. Determine experimentally the strength of current in each branch and what per cent. of the whole current it is.

Prepare a table showing how your calculated and experimental results agree.

### The Shunt Method of Controlling Currents.—

When any E. M. F. acts through a circuit it is found that there is a gradual fall of potential from one part of the circuit to another. In fact it can be easily demonstrated experimentally, that the fall of potential between any two points in the circuit is proportional to the resistance between them. If we let  $R$  = whole resistance of the circuit.  $R'$  = resistance between any two points of the circuit.  $PD$  = whole potential difference; then the difference of potential  $P'D'$  over the resistance of  $R'$  will be determined by the following proportion:

$$PD : P'D' :: R : R'$$

It is evident from this that by varying the value of  $R'$ ,  $P'D'$  will be correspondingly changed.

This principle readily adapts itself to the regulation of currents for therapeutic uses, especially the commercial currents which cannot be well regulated by the use of resistance alone. Several forms of **current controllers** and **rheostats** employing this principle are on the market, and their efficiency in permitting a gradual increase of current through the patient and then of again gradually reducing

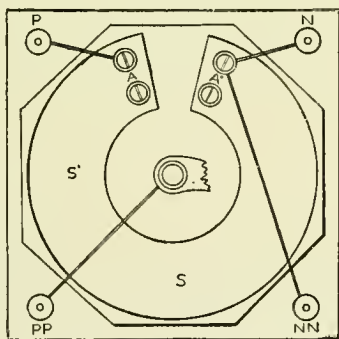


Fig. 22. Diagram of Graphite Shunt Rheostat. See pg. 35.

it to zero before removing the electrodes is certainly such as to recommend them to a more extended use.

It is, perhaps, necessary to say, that such instruments *may* be used to control *all* forms of current electricity applied directly to the body, the resistance in this case being

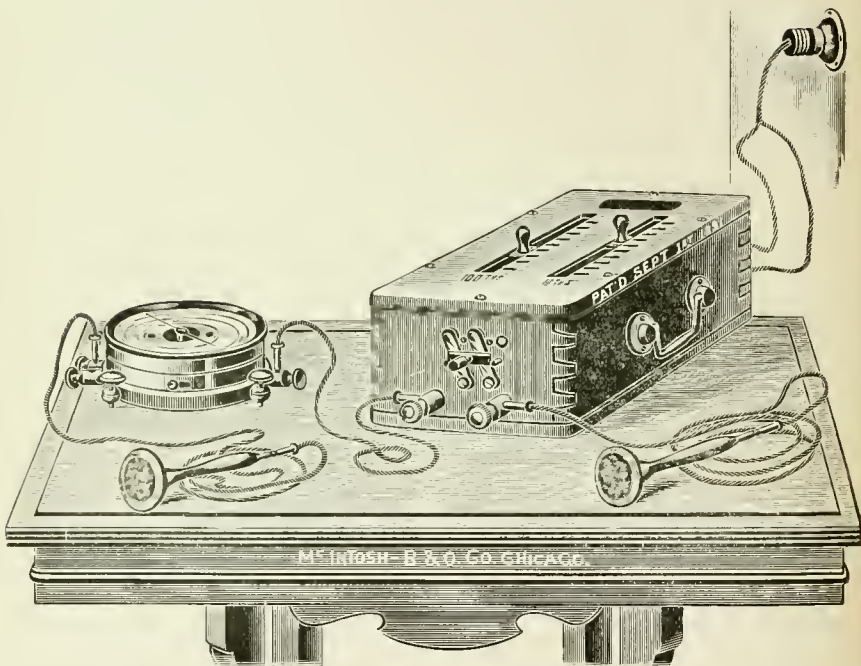


Fig. 23. Shunt Controller for Dynamo Currents.

comparatively great. They are not so readily adapted to control the stronger currents required by the cautery or exploring lamp.

#### CURRENT DENSITY.

**Current density** may be defined as the quantity of current per unit surface of the electrode. Thus a current of 1 milliampere entering the body from an electrode

whose active surface is 1 square centimeter, may be temporarily considered as the unit of current density in electro-therapeutics. Consequently, in the application of a given current to the body, the density of the current varies inversely with the active surface of the electrode employed. Except in such cases when the destructive electrolytic action of the current is desired it is necessary to cover a metallic electrode with some moist conducting material and so place it upon the skin that the current shall flow uniformly through all parts of the electrode.

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## ELECTROLYSIS.

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The process of separating a compound chemical substance into its constituents by passing an electric current through it is called **electrolysis**. The substance thus decomposed is called an **electrolyte**. The electrolyte is always decomposed into at least two simple products called "**ions**." The plate or surface at which the current enters the electrolyte is called the **anode**, that by which the current leaves being called the **cathode**. The "**ions**" collecting at the anode are **anions**, while those at the cathode are **cathions**.

The quantity of the electrolyte decomposed is directly proportioned to the quantity of electricity passed through it—that is, to the current multiplied by the time—and the decomposition takes place at the same rate at all parts of the circuit. A direct current is accurately measured by determining experimentally the rate at which it effects electrolysis. Thus the **ampere** is that current which will deposit on the cathode .001118 grams of silver per second from a solution of a silver salt. The same current will

decompose a grain of water in twelve minutes or will deposit  $\frac{3}{16}$  of a grain of copper from  $\text{CuSO}_4$  per minute.

An ion instead of remaining free may combine either with the electrode or with the electrolyte, forming a secondary product. In general, in the electrolysis of the salts of the alkali-metals, caustic alkali and hydrogen appear at the cathode while free acid and oxygen appear at the anode. Salts of the heavy metals usually give a deposit of that metal at the cathode and a free acid and oxygen at the anode. (T. 235).

In performing the following experiments perfect *cleanliness* is necessary as slight traces of acid on the fingers or table may interfere with the results of the experiment.

EXPERIMENT 45.—Attach platinum electrodes to the poles of the experimental battery and have the galvanometer, B terminals, in circuit. Immerse the platinum of the electrodes in a glass of distilled water. Observe the strength of current and see whether you can observe any traces of decomposition of the water. Now, add a few drops of strong  $\text{H}_2\text{SO}_4$  and notice the changes that take place in the fluid.

In this and the following experiments where chemical changes are involved *write formulæ showing the nature of the changes.*



Fig. 24. Uterine Electrodes for Electrolysis.

EXPERIMENT 46.—Electrolize a solution of  $\text{CuSO}_4$  first using platinum and then copper electrodes. Employ two cells of your battery and measure the current in each

case. The electrodes should be of the same size and should be kept at the same distance apart throughout the experiment. How do you account for the variation of the current in the two cases? Try the experiment with only one cell. (T. 487).

EXPERIMENT 47. — Electrolyze a solution of  $\text{CuSO}_4$  using platinum electrodes. Notice the deposit of copper on the cathode. This illustrates electro-plating, other metals being deposited from solutions of their salts in a similar manner. Hydrogen and the metals travel with the current and are found on the cathode while oxygen and the non-metals always collect at the anode. Determine by this method the polarity of the terminals x and y on the side-table.

EXPERIMENT 48.—You can prove that the copper of the anode is dissolved by using the copper covered platinum as anode in the electrolysis. In a short time the copper will have disappeared. Tarnished copper will become bright by being worn away at the anode while the cathode increases in weight from the depositing of copper upon it. Dissolve the copper deposit on the platinum by dipping the latter in strong  $\text{HNO}_3$  found on the side-table.

EXPERIMENT 49.—Electrolyze a solution of sodium sulphate ( $\text{Na}_2\text{SO}_4$ ) using platinum electrodes. What gases are liberated? Is there a decomposition of the salt? Are the gases primary or secondary products of decomposition? Make yourself familiar with the various chemical changes taking place and write the chemical equations.

EXPERIMENT 50.—Place some neutral  $\text{Na}_2\text{SO}_4$  solution colored with litmus in a V tube and pass the current through the electrolyte a few minutes, using platinum electrodes. Notice the evolution of gases as before, also that the solution becomes blue about the cathode and red

about the anode indicating the formation of free acid and free alkali.

EXPERIMENT 51.—Having your hands clean and of perfectly neutral reaction, lay a piece of blue litmus paper on the palm and a red piece on the back of the hand. Wet both pieces with a neutral solution of  $\text{Na}_2\text{SO}_4$ , press clean copper electrodes against them and allow the current to flow from the palm to the back of the hand. Use 8 cells of your battery and allow the current, which is quite weak, to flow for about 10 minutes. Notice that the papers have changed color.

EXPERIMENT 52.—Repeat EXP. 51, but this time carefully cover the electrodes with absorbent cotton moistened with the neutral  $\text{Na}_2\text{SO}_4$  solution. If the experiment is properly performed the litmus paper on the hand will not change color, but a piece in contact with the metal of the electrodes will change color. The strength of current being weak you should allow it to flow long enough to give marked results.

This experiment shows the value of covered electrodes and suggests the rule:

*When using the galvanic or direct current, never place bare or non-porous electrodes in contact with the skin or mucous membranes unless you wish to obtain at the points of contact the effect of free acid or free alkali.*

EXPERIMENT 53.—Electrolize a solution of  $\text{NaCl}$ , using carbon electrodes. Notice the odor of free chlorine. Now, use iron electrodes and notice that less chlorine is given off, but that the anode is being corroded, giving a light colored solution of iron salt near the anode. Finally the alkali liberated at the cathode will pass over by diffusion and cause a precipitate of ferrous and ferric hydrates. *Iron salts cause more or less discoloration of*

*the tissues in which they are set free.* For this reason in minor surgical operations such as the removal of superfluous hairs, moles, warts, etc., especially on the exposed

parts of the body, the cathode rather than the anode should be employed.

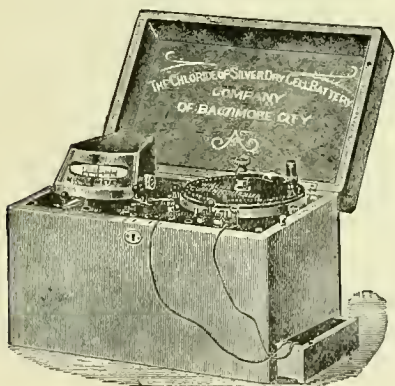


Fig. 25. Chloride of Silver Battery.

before closing the circuit by placing the battery plates in the liquid. Upon closing the circuit observe the galvanometer needle and explain why it returns to zero so quickly. (T. 487). Now use one of your bichromate cells in a similar manner and explain the difference in behavior.

EXPERIMENT 55.—Polarized electrodes constitute an independent source of E. M. F., which acts in an opposite direction to that of the electrolyzing current. This can be shown in the following manner. Place in circuit with your galvanometer the entire experiment battery coupled in series and a pair of clean copper electrodes between which is a layer of absorbent cotton wet with a neutral solution of  $\text{Na}_2\text{SO}_4$ . Allow the current to flow a few minutes, observe the deflection and then break the circuit by raising the battery plates. Wait till the needle comes to rest and then connect the wires attached to the battery terminals, thus making a circuit including only

the electrodes and galvanometer. Notice the amount and direction of the deflection.

EXPERIMENT 56.—Remove a few hairs from the back of your hand by electrolysis, using a fine sewing needle as the electrode. The anode, which should be of medium size and covered with absorbent cotton soaked with a saline solution, may be placed upon any convenient surface, as on the muscular part of the forearm or the palm of the hand. Introduce the needle along a hair into the hair follicle, have the galvanometer, B terminals, and battery in circuit and then complete the circuit by placing



Fig. 26. Needle Holder for Electrolysis.

the anode in position. The person operated on can be taught to vary the strength of current both by pressure upon the electrode and by varying the amount of surface in contact with the anode. If properly done a little froth will appear around the needle and the hair will come out easily. Determine what was the greatest strength of current during the operation. Try the effect of having all parts in position and then suddenly turning on the current by immersing the battery plates. Which do you consider the better method?

In the actual electro-therapeutic practice, some form of **graduated rheostat** or **controller** should be employed so as to permit the gradual entrance and withdrawal of the current when the circuit is completed, with the patient forming a part of it. By this means all unpleasant shocks are avoided.

EXPERIMENT 57.—It is often necessary in electrolytic work that only a limited portion of the tissue should be

exposed to the action of the current or that the skin should be protected from the caustic products at the point of insertion of the electrodes. In such cases all but the tips of the needles can be insulated by dipping them into alcoholic shellac, protecting the tips by small pieces of cork. Dry over a gas burner heating enough to drive off all traces of alcohol and secure an even coating over the surface. In removing a growth, requiring the insertion of both electrodes, it will be found that the anode cannot be easily withdrawn. If the current be reversed for a short time the tissue about the electrode will soften and it can then be removed without injury to the tissues.

EXPERIMENT 58.—Electrolize a piece of fresh meat which retains its juices, employing steel needles as electrodes. Observe and describe the effect at the point of

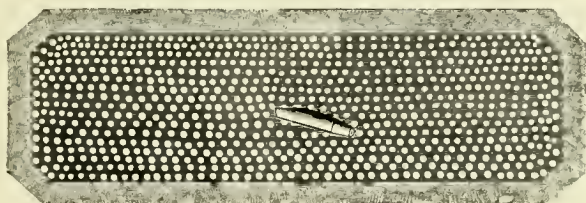


Fig. 27. Dispersing Electrode.

insertion of both the anode and cathode needles. Inserting each needle one inch and keeping them one inch apart, determine the resistance in ohms of the fresh tissue between them.

EXPERIMENT 59.—Take 4 glasses out of your experimental battery and wash them clean, then fill each half full with a neutral  $\text{Na}_2\text{SO}_4$  solution containing a little alcoholic solution of phenol-phthalein, and arrange them in a row. Connect the remaining four cells of your battery in series and connect the wires of this battery to the end glasses containing the phenol-phthalein so that the wires

dip into the fluid at the sides of the glasses. Complete the circuit through the remaining glasses by short pieces of copper wire, allowing the fluid in each glass to form as wide an interval in the circuit as possible. Measure the strength of current passing and also note the change of color in the cells throughout the row after the current has passed for a few minutes. Phenol-phthalein is a delicate test for the presence of an alkali. Why should this electrolytic change take place in the middle glasses with which the terminal wires are not in contact? Is the amount of chemical action the same in each of the four electrolytic cells?

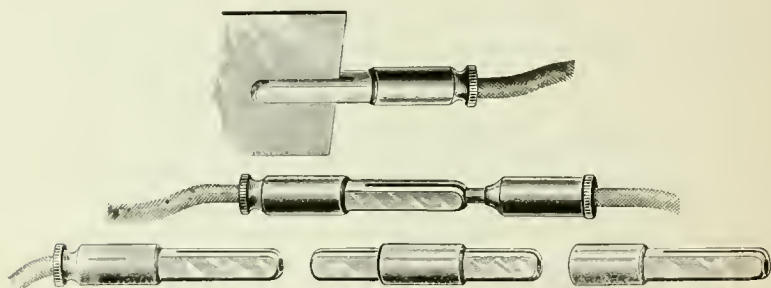


Fig. 28. Universal Connectors.

**Laws of Resistance.**—In the solution of the problems here given, the following brief summary of the laws of resistance should be borne in mind:

1. The resistance of conductors of the same material and thickness varies directly as the length.
2. The resistance of conductors of a given material and length varies *inversely* as the area of cross section. Areas of circles are proportional to the square of their diameters.
3. The resistance of a wire of a given length and diameter depends upon the material of which it is made—that is, upon the *specific resistance* of the material.

## PROBLEMS.

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The following problems are given with the view of putting into practice the facts and principles that have been treated of in the preceding experiments. To these others will be added when needed for the purpose of illustrating or emphasizing certain rules or facts that may not seem to be fully grasped by the student.

PROBLEM 1.—A certain battery whose  $r$  is .5 ohms gives a current of 1 ampere through a  $R$  of 4 ohms. What is its E. M. F.?

PROBLEM 2.—A battery of 40 cells each having an  $r$  of .4 ohms is arranged 8 in series and 5 in multiple arc. If the current flowing through a wire of no appreciable resistance is 31.2 amperes, what must be the E. M. F. of each cell? What is the strength of current through each cell?

PROBLEM 3.—Twenty cells in multiple arc, each having a  $r$  of 30 ohms, send a current of  $\frac{1}{3}$  ampere through an external resistance of 1.5 ohms. What is the E. M. F. of each cell?

PROBLEM 4.—Find the current flowing through a circuit composed of a galvanometer having a  $R$  of 100 ohms, a battery which has an E. M. F. of 6 volts, and having a  $r$  of .8 ohms, and connecting wires with a  $R$  of 5 ohms.

PROBLEM 5.—The E. M. F. of a cell is 1.8 volts and its  $r$  .06 ohms. Would 5 of these cells in series light an incandescent lamp which has a  $R$  of 10 ohms, and which requires .8 amperes of current? How many milliamperes of current are furnished?

PROBLEM 6.—Five cells, each having an E. M. F. of

2.5 volts, and a  $r$  of .2 ohms are joined first in series and then in multiple arc. Find the difference in the strength of current if the  $R$  of the conducting wires is practically zero.

PROBLEM 7. Find the current from 24 cells arranged 6 in series and 4 in multiple arc if the E. M. F. of each cell is 1 volt and the  $r$  of each cell 3 ohms, the  $R$  being 45 ohms.

PROBLEM 8.—Take 15 cells, each having an E. M. F. of 1.5 volts and a  $r$  of .2 ohms. What would be the current strength if three of the cells were joined in opposition to the other twelve?

PROBLEM 9.—A battery whose E. M. F. is 6 volts and whose  $r$  is 2 ohms sends a current of 1400 milliamperes. What must be the resistance offered in the circuit?

PROBLEM 10.—A battery of 5 cells in series, each cell having an E. M. F. of 2 volts, produces 2 amperes of current when the external resistance ( $R$ ) is 3 ohms. What is the  $r$  of each cell?

PROBLEM 11.—The E. M. F. of a cell is 1 volt, its internal resistance ( $r$ ) 2 ohms. How many such cells joined in series will be necessary to send a current of 55 milliamperes through an external resistance of 890 ohms?

PROBLEM 12.—If the  $r$  of a cell is 1 ohm and you have 90 such cells, how should they be connected so as to send the strongest current through an external resistance of 10 ohms?

PROBLEM 13.—If the E. M. F. of a cell is 2 volts, and its internal resistance 4 ohms, what would be the least number of such cells required to send a current of 1 ampere through an external circuit offering a resistance of 15 ohms?

PROBLEM 14.—What is the best way to connect 12

cells, each having an E. M. F. of 1 volt and an internal resistance of 3 ohms, in order to send the maximum current through an external resistance of 30 ohms?

PROBLEM 15.—If the R of 700 yards of copper wire is .91 ohms, what will be the R of 1320 yards?

PROBLEM 16.—The R of a certain copper wire is 4.55 ohms. The R of a mile of this same wire is 1.3 ohms. What is the length of the piece?

PROBLEM 17.—If the R of 130 yards of copper wire  $\frac{1}{8}$  of an inch in diameter is 1 ohm, what is the resistance of the same length of copper wire  $\frac{1}{2}$  of an inch in diameter?

PROBLEM 18.—What is the R of a mile of copper wire which has a diameter of 65 mils, if the R of a copper wire 80 mils in diameter is 8.29 ohms? (A mil is  $\frac{1}{1000}$  of an inch).

PROBLEM 19.—What length of copper wire 4 mm in diameter would be equivalent in resistance to 12 yards of copper wire 1 mm in diameter?

PROBLEM 20.—Find the joint R of two wires offering respectively 5 and 7 ohms resistance.

PROBLEM 21.—The joint resistance of two wires is 3 ohms and one of them has a resistance of 9 ohms. What is the resistance of the other?

PROBLEM 22.—What must be the resistance of the shunt used with a galvanometer whose resistance is 4500 ohms so that the resistance of the shunted galvanometer shall be 450 ohms?

PROBLEM 23.—Find the joint resistance of three wires offering respectively 5, 11 and 15 ohms.

PROBLEM 24.—Three wires in a divided circuit have resistance of 6, 7 and 15 ohms respectively. How would a current of 1 ampere divide in this circuit?

PROBLEM 25.—Three wires in divided circuit have a joint resistance of 6 ohms. What resistance must be used as a shunt to reduce the joint R to 3 ohms?

PROBLEM 26.—A galvanometer whose resistance is 5000 ohms is shunted by a wire having a resistance of 500 ohms. If a current of 30 milliamperes is sent through the circuit what will be the strength of current through the galvanometer?

PROBLEM 27.—If a current of 20 ma. is passed through the body, the anode a circular disk of metal 3 centimeters in diameter applied to the neck, the cathode 10 centimeters square placed on the abdomen, what would be the density of current per centimeter of surface at the anode? What amount of electric energy (*Watts* i. e.,  $C. \times E. M. F.$ ) would be expended at the anode in 10 minutes of time, provided the R at that point is one-fourth of the entire resistance?

PROBLEM 28.—If the R, including a portion of the body, is 3500 ohms and the skin contact with the electrodes furnishes 3000 ohms of this resistance, how much electric energy would be expended at the skin contact in a treatment lasting 15 minutes when the voltage is 50? What would be the result? How is that result to be avoided?

PROBLEM 29.—When two electrodes each 3 centimeters square are used to conduct a current of 12.5 ma. at a voltage of 70 through the spine, one electrode being placed on the back of the neck and the other over the sacrum, how much electric energy reaches the deep tissues of the body if the skin contacts furnish two-thirds of the entire resistance? How could the amount of energy expended on the deeper portions be increased without changing the voltage?

## PHORESIS, ANAPHORESIS, CATAPHORESIS.

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It has long been known that the direct electric current has a marked mechanical effect in carrying certain liquids and solutions through porous partitions or membranes so as to either accelerate or retard the ordinary processes of osmosis. This effect, probably very closely related to that of electrolysis, is generally such as to convey the substances in solution in the liquid through the dialyzing partition or membrane in the direction of the current, thus causing a decreased anodal and an increased cathodal pressure, although in some instances the reverse of this is true. These phenomena, which are most manifest in badly conducting liquids, are generally included under the term **electric osmose** but when applied to living animal tissues for therapeutic purposes are called **cata-phoresis** or **anaphoresis** according to the direction in which the substance is conveyed.

The numerous experiments of De la Rive established the following generalizations regarding electric endosmose:

“The force with which a galvanic current transports a liquid through a porous partition from the positive to the negative wall is measured by a pressure which is directly proportional to the intensity of the current, to the electric resistance of the liquid, to the thickness of the porous partition, and inversely proportional to the surface of that partition.”



Fig. 29 Phoresis electrode.

EXPERIMENT 60.—The passage of substances into or out of the tissues of the body may be hastened by electric osmosis, that is by the anaphoric or cataphoric action of the current. Thoroughly wash your hands with soap and

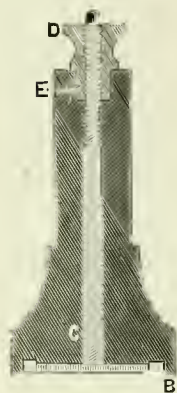


Fig. 30 Section of Phoresis Electrode.

water, then place on the back of each wrist a square cotton-covered electrode which has been saturated in a solution of methylene blue. Now pass the current from your 8-cell battery through the body from wrist to wrist. Measure carefully the current and allow it to flow till the equivalent of 5 ma. has passed for 10 minutes. Discontinue the current and again wash the wrists and examine whether there is any difference in the discoloration of the skin which was under the anode and cathode.

EXPERIMENT 61.—Repeat the last experiment employing a cathode moistened with a solution of common salt and a metallic or better a carbon anode separated from the skin by two small squares of blotting paper soaked in a 4 per cent. solution of cocaine hydrochloride. The current should be measured carefully and permitted to pass for at least ten minutes. When it is discontinued the part under the electrode should be examined to see whether any local anæsthesia has been produced. This can be tested by pricking the surface with a needle.

Electric osmosis, either as anaphoresis or cataphoresis, is employed in electro-therapeutics for

1st. Conveying medicines in solution into the tissues through the skin or mucous membrane surfaces. This can be made local or general medication according as a

limited area or the entire skin surface is subjected to the action;

2nd. Removing injurious substances from the tissues, abnormal accumulations of fluids in joints, dropsical effusions, etc.

Cataphoresis is at present much used by the dentist to obtund sensitive dentine. The anodal effect of the current is of itself sedative but its anæsthetic action is greatly increased when a substance, which is soothing to sensory nerves and is capable of being conveyed into the tissues by means of cataphoric action, is used in solution on the anode.

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#### PHYSIOLOGICAL ACTION OF DIRECT CURRENTS.

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There are certain reactions which direct or galvanic currents bring about when applied to living animal tissues which cannot be regarded as physical or mechanical effects of the current, since they are dependent upon the peculiar properties of living animal tissues and the nature of their response as such to this form of stimulant or excitant. These it seems proper to designate as **physiological effects**, and as they have long served as a rational basis for therapeutic applications with this form of current a special mention of them is required. The physiological effects that are best known to us from experiments in the physiological laboratory and from electro-therapeutic observations may be classified as:

Reactions of muscular tissue;

Reactions of nerve tissue;

Reactions of protoplasm.

Both the striped and unstriped varieties of muscle can be caused to contract by the application to them of

either pole of a direct current, the other pole being placed upon some distant point of the body to complete the circuit. The strength of the response in normal muscle will depend upon the strength and electro-motive force of current used. This form of current causes a contraction only at the moment when it is closed or opened; at the "make" and "break" of the currents as they are called. The reactions in unstriated muscle resemble, in general, those of the striped variety except that unstriated muscle responds more slowly to the stimulation.

The results following the application of the direct current to nerve tissue differs according to the nature of the tissue influenced *i. e.*, whether it is peripheral nerve, sensory, motor, secretory or nerve cells in brain, cord, or ganglia. Thus, applications along the course of a motor nerve will cause contractions in the muscle supplied by that nerve similar to those obtained by the direct application to the muscle itself.

Sensory nerves respond to direct current applications by increase or decrease of excitability, according as the application is made with the anode or cathode. The result of anodal application is to decrease the excitability and the effect is called **anelectrotonus**. The result of the cathodal application, on the other hand, is to increase the excitability and this effect is called **catelectrotonus**.

EXPERIMENT 62.—Join two experimental batteries in series, put in circuit the galvanometer, B terminals, a circuit breaker, pole changer and a high-resistance rheostat. Use a large dispersing cotton-covered electrode and a small active electrode which should be applied over the median nerve above the elbow joint. By means of the pole-changer the small electrode can be quickly changed from anode to cathode and the current strength can be

readily changed by means of the rheostat. Carefully determine the strength of current that will produce:—

1. Cathode closing contraction (C. C. C.).
2. Anode closing contraction (A. C. C.).
3. Anode opening contraction (A. O. C.).
4. Cathode opening contraction (C. O. C.).

This experiment may be done by four students working together. Make a sketch of the entire circuit.

EXPERIMENT 63.—Apply two cotton-covered electrodes about 1.5 inches square to corresponding parts of the flexor surface of each forearm. Place a rheostat, galvanometer and a 16-cell battery in circuit and allow a current of 10 ma. to flow for at least 5 minutes. After the electrodes have been removed apply the points of a pair of compasses to the two surfaces and in each case determine the distance between the points in millimeters at which they can be distinguished by sensation alone. Can you detect any difference in the sensibility of the two surfaces? Also note any difference in the external appearance of the two surfaces which were under the influence of the current.

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### CATALYSIS.

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The term **catalysis** was first employed by Remak to include the various processes, partly demonstrable and partly theoretical, which attended the application of a direct current to diseased tissues and which often resulted in a restoration of normal function. These processes are both physical and physiological, some of them being of a very complex nature.

It is believed that neither the electrolytic, cataphoric,

anaphoric, contractile, nor electrotonic actions of the direct current which have already been described are sufficient to account for the permanent benefit which the employment of such currents in therapeutics affords. It is assumed therefore that there are a variety of effects not yet experimentally demonstrable but still theoretically quite probable, that follow from the passage of the current in addition to these that can be readily observed, *and it is both these known and assumed actions that the word catalysis is intended to cover.* The result you obtained in EXP. 59 will serve, in a measure, to illustrate this interpolary action of the direct current when passed through the living organism.

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### THE GALVANO-CAUTERY.

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The energy of an electric current may manifest itself in a variety of ways, such as magnetic, mechanical, chemical and radiant energy, the latter including various phenomena among which the most common are heat and light. In every case where a current is controlled by the introduction of resistance into the circuit, without a counter electro-motive force such as is furnished by an electric motor or an electrolytic cell, the energy is used up in the form of heat. In the vast majority of electrical operations the heating effects of the currents are wasteful and are, so far as possible, avoided or reduced to a minimum. The electric cautery is one of the appliances in which this property of the current can be utilized. The amount of heat developed in a conductor is proportional—

1st, to the resistance;

2nd, to the square of the strength of current; and

3d, to the time.

The temperature to which a body of a given resistance will be raised by a given current depends upon the nature of the resisting substance, *i. e.* upon its specific heat, and also upon the form of the conductor. The temperature will continue to rise till the rate at which it is lost by conduction, convection and radiation is equal to the rate of generation by the current.

From these general considerations it becomes evident that all parts of the circuit in cautery work should have the least possible resistance except the part which is to be heated. For this reason cautery batteries are made of large plates placed very close together and all the necessary conducting wires are relatively large and of low resistance (T. 426—429).

EXPERIMENT 64. —To show the necessity of a strong current in working with the cautery, connect the poles of your battery, arranged two in series and four in multiple arc, by ten inches of No. 36 copper wire. Observe to what extent the wire is heated and then slowly shorten it and notice whether the temperature rises. Repeat, this time using german silver wire of the same length and diameter.

EXPERIMENT 65.—Show the necessity of having a low internal resistance by using first one cell of the experimental battery and then one of the large bichromate cells on the side table, in each case passing the current through the german silver wire used in the last experiment. Is the effective E. M. F. in the two cells the same after the current has been flowing a few minutes? Give your reasons.

EXPERIMENT 66.—Twist together three pieces of iron or german silver wire six inches in length and pass the current of your battery joined in multiple arc through it. Notice the rise in temperature. Now replace the

twisted strand by a single wire two inches in length, and see whether the temperature is higher than before. Is the strength of current the same in the the two cases? How do you explain the difference in the results? (T. 429).

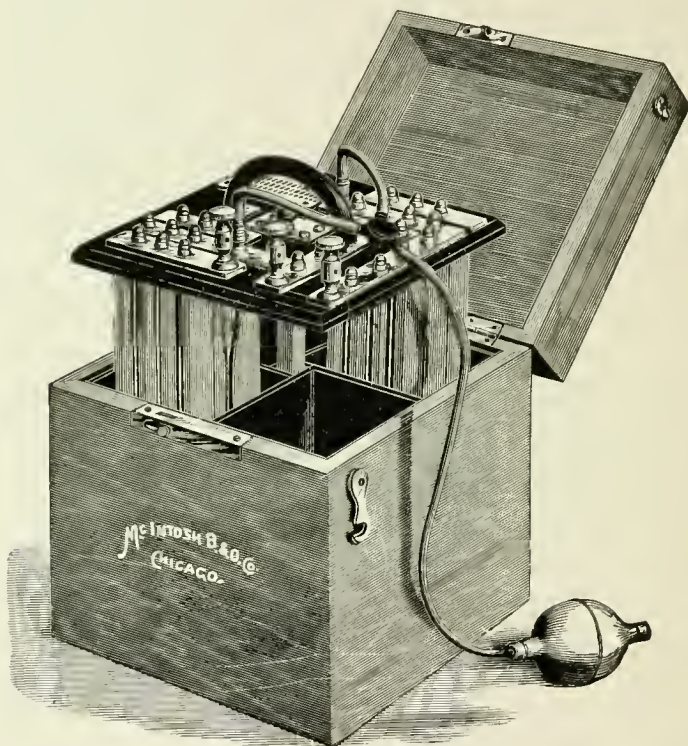


Fig. 31. Primary Battery for Cantery Work.

The heat generated in the two cases should be exactly the same but the mass of metal and surface exposed in the two cases are very unequal. It should be apparent that wires having a high specific resistance and which do not easily corrode are best adapted for use in the cautery. Platinum meets these requirements and has the additional

advantage of not being easily fused; even it, however, can be melted by the electric current.

EXPERIMENT 67.—Make a small cautery electrode like the model shown you. Connect it to one of the large bichromate cells. What causes the rapid falling in temperature after the current has been flowing a few minutes? Notice the effect of raising and lowering the plates in the fluid. Examine the two forms of cautery batteries and the methods of controlling the current in each. It is evident that the plates should be left in the fluid only so long as the cautery is in immediate use. Could you heat a cautery with six Daniell cells?

EXPERIMENT 68.—Use one of the cautery batteries to heat the cautery electrode and when it is glowing, immerse part of it in water and notice the effect on the remaining part of the fine wire. What is your explanation? A similar effect attends the use of the cautery in practice and unless a ready means of regulating the current is at hand, it may be melted (T. 404).

#### SOURCES OF CURRENT FOR THE ELECTRIC CAUTERY.

The strength of current required for heating electric cauteries varies from 1 to 25 amperes. This current is far in excess of that used in therapeutics when the current traverses the body, and for this reason special forms of generators and controllers are required for doing cautery work. A suitable current may be obtained from:—

1. Primary batteries.
2. Secondary or storage batteries.
3. The dynamo.

**Primary Batteries.**—Since the external resistance in a cautery circuit is very small (seldom exceeding .1 ohm) it is necessary that a cautery battery should be

specially constructed so that its internal resistance shall be reduced to a minimum. The E. M. F. may vary from 2 to 6 volts. In order to diminish the internal resistance of a battery, the plates should be large and near together and every precaution should be taken to prevent polarization. If cells of large size are inconvenient and make the battery too cumbersome, smaller cells may be em-

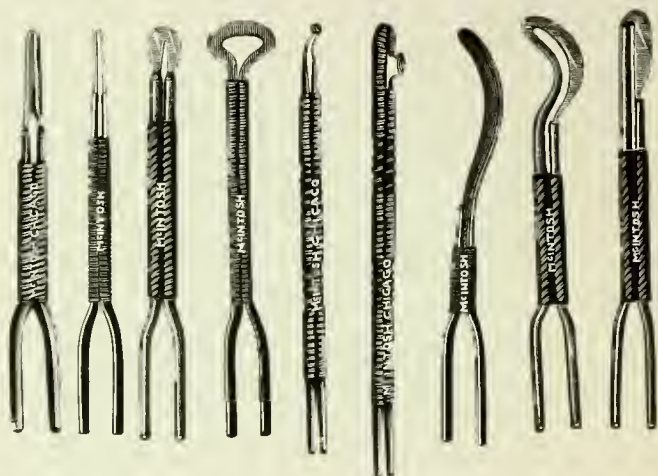


Fig. 32.

ployed provided they are joined in multiple arc. By using a large bichromate cell with large plates of carbon and zinc the resistance may be brought down to .15 ohms. This cell acting through a cautery electrode of .1 ohm resistance would furnish 8 amperes of current.

$$C = \frac{E}{R + r} \quad C = \frac{2}{0.1 + 0.15} = \frac{2}{0.25} = 8 \text{ amperes.}$$

In all forms of primary batteries which generate large currents, polarization soon tends to lessen the output of current. This difficulty may be prevented by keeping the

plates of the battery constantly in motion, thus bringing fresh battery fluid in contact with the plates. By having at the outstart a current capacity far in excess of the amount required to heat the cautery, a suitable rheostat in circuit to regulate the current to the required amount would be the most convenient method of overcoming the polarization effects.

**Secondary or Storage Batteries.**—A well constructed and newly charged storage battery furnishes an ideal source of current for cautery purposes. The current should be controlled by a rheostat such as has already been mentioned. The care of a storage battery and the uncertainty of its charge at any time are drawbacks which prevent its general use by physicians.

**Dynamo Circuits.**—The currents from both direct and alternating current dynamos may be controlled by heavy wire resistance for heating electric cauteries. This is however a cumbersome and expensive method.

When, however, these currents are changed by transformers they become the most convenient sources of current for electro-cauteries and exploring lamps, this being especially true of the transformed alternating current.

Attention will be given to these methods of transformation of dynamo currents further on in this work.

## SOURCES OF CURRENT FOR ELECTRIC LIGHT.

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The electric light possesses marked advantages over all other means for illuminating the cavities of the body. In general, it may be stated that the sources of current for electric cauteries will also serve to light the exploring lamps used for diagnosis or illumination. The conditions of the circuit are, however, somewhat changed and these demand corresponding changes in the source of the current. Thus, the resistance of the filament of the small lamps varies from 6 to 30 ohms. The current strength required to raise these lamps to incandescence is from 3. to 1.6 amperes. Thus a greater E. M. F. is necessary than for heating a cautery and the internal resistance becomes a factor of very much less importance. A battery of 10 bichromate cells in series, when  $r = 1$  ohm, would send a current of 1 ampere through a lamp of 10 ohms resistance.

$$C = \frac{2 \times 10}{(1 \times 10) + 10} = \frac{20}{20} = 1 \text{ ampere.}$$

In lighting lamps to be used in diagnosis it is necessary that the current be controlled either by a rheostat or by some ready means for varying the E. M. F. acting through the lamp. The transformed alternating

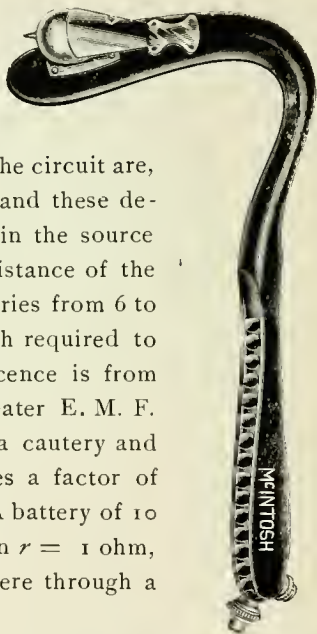


Fig. 33 Tongue depressor and throat illuminator.

dynamo current is a most desirable and convenient source to employ for this purpose.

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## THE STORAGE OR SECONDARY BATTERY.

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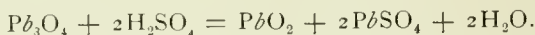
As was seen in EXP. 55, a difference of potential exists between two like plates immersed in a liquid, by virtue of the products of electro-chemical decomposition set free at their surfaces. Such cells are known as storage cells or accumulators. The E. M. F. of the accumulator depends upon the tendency for the liberated "ions" to recombine and its magnitude is strictly proportional to the energy with which this recombination tends to take place. Thus, in the electrolysis of water, the elements O and H by their recombination yield an E. M. F. of 1.47 volts and consequently no cell or other source of current can effect the electrolysis of water unless it has an electromotive force of, at least, 1.47 volts. It should be borne in mind that it is not electricity but chemical energy which is stored up by the current and that the latter under proper conditions is again reconverted or transformed into the energy of an electric current. In the progress of development of the storage cell two main problems were presented, viz:—

1. How to retain a large amount of the liberated "ions" upon the two electrodes,
2. How to prevent the dissipation of the energy while the cell is on open circuit.

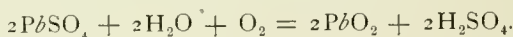
Considerable advancement has been made in recent years but the second problem has proved to be far the more difficult to solve.

Great care must be exercised in the handling of a storage battery as an accidental "short circuit" is very destructive to the plates. In charging the cell the directions of the manufacturer should be strictly observed and where practicable it is best to entrust this task to the manufacturer or to some local electrician.

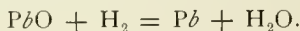
A recent form of storage battery is one consisting practically of two lead plates, the positive of which is intimately covered with red lead (minium,  $Pb_3O_4$ ) and the negative with litharge ( $PbO$ ). The electrolyte is sulphuric acid, one part by weight to four of water. As soon as the plates are immersed in the fluid the following reaction takes place. The lead oxides are converted into lead sulphate.



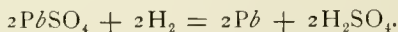
The changing current liberates hydrogen and oxygen. The latter goes to the positive plate and changes the lead sulphate to lead peroxide and sulphuric acid.



Hydrogen goes to the negative plate and changes the lead monoxide to spongy lead with the formation of water.



It also acts upon the lead sulphate, changing it to spongy lead and sulphuric acid.



The chemical reaction of the discharge is the formation of lead sulphate upon both plates.

EXPERIMENT 69.—Construct a storage battery, using lead plates with a paste made of lead oxide and sulphuric acid (1:4), held in place by a layer of absorbent cotton.

Roll the plates tightly together, being careful to have them completely covered with cotton, and then immerse in the sulphuric acid solution. To get good results it is advisable to first charge and then discharge the battery. First pass the charging current in one direction, then reverse the current and finally pass it again in the first direction. Connect the plate covered with lead to the positive pole while charging. When your accumulator is finally charged have its E. M. F. measured and then proceed to determine its internal resistance by Ohm's law. From these results compute the current which the cell would furnish when working on short circuit.

NOTE. — Your experimental battery must be in good condition for charging and it is well to join it 2 in multiple arc and 4 in series. The time required for each charge and discharge should be at least 10 minutes. The galvanometer may be used to assure you that you have a charging current and to detect any variations in the same.

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## THE ROTARY TRANSFORMER.

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The rotary transformer shown in the accompanying figure is a device for changing the ordinary direct dynamo current of high voltage to a direct current of low voltage such as is suitable for heating cautery wires and lighting exploring lamps. The machine is virtually an electric motor and dynamo combined, the current supplied to the motor being of a higher E. M. F. than that furnished by the dynamo. Except for a slight loss in transformation the energy ( $C. V = \text{current} \times \text{potential difference}$ ) supplied to the machine and that yielded by it should be equal. The old method of controlling dynamo currents for cautery work by introducing heavy wire resistance in

circuit is both very cumbersome and expensive since less than 10 per cent. of the energy is usefully employed.

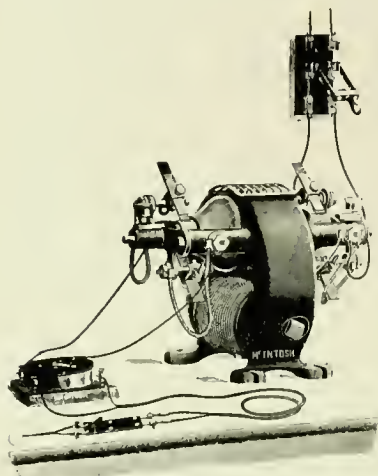


Fig 34. Rotary Transformer.

A similar waste of energy can be obviated by charging storage batteries with the transformed current instead of employing the ordinary dynamo current controlled by resistance.

A suitable rheostat must be employed in the cautery or light circuit for the purpose of controlling the current more accurately.

The rotary transformer is not only a convenient and economical means for securing a direct current for therapeutic purposes but it is also a safe means. When taking a supply of current for therapeutic purposes from dynamo mains carrying a current of high voltage all danger of subjecting a patient to an excess of current or voltage is entirely removed by this device.

## MAGNETISM.

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A close relationship exists between current electricity and magnetic phenomena. Induced current electricity, which plays a very important part in therapeutics, is the result of magnetic action. There is also good reason to believe, from the results of recent investigations, that magnetism itself has some direct therapeutic value. At least we have discovered from experiments conducted for a number of months in this laboratory that the growth of growing animals is accelerated when subjected for some time to the influence of alternating magnetic fields. These considerations render it advisable for us to review by experiment the fundamental phenomena relating to the relationship between electricity and magnetism.

In performing the following experiments certain facts should be kept in mind:

1. Rough and careless handling of a permanent magnet is very detrimental to its strength and may destroy its usefulness;
2. The swinging needle of the galvanometer may have its magnetic properties changed or destroyed by bringing strong magnets too near it and thus the instrument may be rendered quite useless.

EXPERIMENT 70.—Upon a smooth white surface place a small quantity of iron filings. Bring a soft iron bar in contact with them and notice whether they attach themselves to its surface. Also bring a steel bar in contact with them and observe whether they behave as before.

EXPERIMENT 71.—Hold the end of the soft iron bar among the filings and while it is there bring a permanent

magnet in contact with the other end; observe whether or not any filings cling to the iron bar. Remove the permanent magnet and observe what takes place. Proceed in the same manner with the hard steel bar. Does it support as many filings as does the iron bar? Do they all drop off on removing the permanent magnet? Try to magnetize the iron permanently by rubbing it with the permanent magnet, also try the same with the steel bar. Note the results. What part of the bar will support the greatest weight? (T. 86).

EXPERIMENT 72.—Float a small magnetized steel bar (a piece of watch spring answers very well) by means of a flat cork in a flat porcelain dish nearly filled with water. Notice that it comes to rest with its ends pointing north and south. (T. 87). When the bar is at rest bring first near its north end and then near its south end a bar of soft iron. Notice in each case the effect on the magnetized bar. Remove the end of the soft bar and see whether the effect differs.

EXPERIMENT 73.—With the steel bar, as in the preceding experiment, bring near its north seeking end first one pole and then the other of a small bar magnet. Notice that the pole that attracts the north seeking end of the floating bar repels the south seeking end and *vice versa*. Remove the bar from the cork and bring the end that pointed north near either end of the galvanometer needle. Notice that it attracts the south seeking end but repels the north seeking end, behaving as did the bar in the first part of the experiment.

EXPERIMENT 74.—Magnetize a piece of watch spring and after determining its polarity, break it in two and see what relation the poles of one piece bear to those of the other (T. 88, 89, 90, 91, 96, 97.). Is it possible to mag-

netize a watch spring in such a manner that it shall have three or more poles? If so explain the process.

EXPERIMENT 75.—Place a smooth piece of paper over a bar magnet which is sunk beneath the surface of a small board. Sift iron filings through a piece of cloth evenly over the surface of paper and tap it lightly. The filings will arrange themselves in well defined curved lines around the magnet. Make a sketch of the magnetic field thus shown. Also in like manner prepare and draw the magnetic fields between two similar and two opposite magnetic poles. What direction is attributed to magnetic lines of force (1) within the magnet and (2) in the magnetic field? Can the *number* of magnetic lines of force in a permanent magnet be *varied* by causing an armature to approach or recede from it? (T. 375-377).

#### MAGNETIC EFFECTS OF THE ELECTRIC CURRENT.

The following are a few of the most important laws relating to the magnetic effects of electric currents:

1. A piece of soft iron surrounded by a coil or helix of insulated wire becomes a magnet and retains that property while an electric current is flowing through the helix.

2. The strength of an electro-magnet is proportional to the strength of current and to the number of turns of wire in the helix—in other words, is proportional to the number of ampere turns. This law is only true so long as the iron *core* is still unsaturated.

3. Upon interrupting the current in the helix the magnetism induced in the iron at once disappears. Nearly all specimens of iron retain a trace of magnetism for a time, the amount retained and the time depending on the quality of the iron. (T. 367, 368).

4. If the iron core or bar be removed from the helix the latter will act, while the current is flowing, like an electro-magnet but to a much smaller degree than when the core is present. If the core be made up of a large number of small bars it will both receive and give up its magnetic properties more readily. (T. 381, 382, 383, 384).

EXPERIMENT 76.—Having a soft iron bar, wind around it from one end to the other an insulated copper wire. Having one end of the bar held in position near some iron filings and a small bichromate cell connected to the wires, observe what takes place upon making and breaking the circuit. Again bring one end of the electro-magnet near the galvanometer needle and on completing the circuit notice that the north seeking end is either attracted or repelled. (Avoid bringing it too near). What is the polarity of the end presented? Present the opposite end of the electro-magnet and see whether the result differs. Rewind the bar in the opposite direction and observe whether the polarity has been changed. *You should be able to deduce the law which shows the relation between the direction of the current around the helix to the magnetization produced.*

EXPERIMENT 77.—With the iron bar used before wind the wire midway between the ends, using the same number of turns and covering not more than one-third of the bar. Compare the strength with that of the covered bar. This can be done by allowing it to pick up small pieces of iron or preferably by observing the deflection produced on the galvanometer needle at a given distance. Place the coil at one extremity of the bar and compare the result with the preceding. In all cases the wire should be evenly and closely wound around the bar, *and in each case the plates*

*of the battery must be removed from the liquid as soon as the observation is made. Why?*

EXPERIMENT 78.—With the coil at one extremity of the bar remove the wire, one turn at a time, and observe each time the change in the strength of the magnet. What are the constant and what the varying factors in this experiment?

EXPERIMENT 79.—Having the coil at one end of the bar either replace the small battery by a large one or introduce a resistance into the circuit without changing the number of turns on the bar. Observe the variation in the strength of the magnet. Would you expect it to vary the same way in either case?

EXPERIMENT 80.—Now with the soft iron bar and the helix arranged as in the preceding experiment, bring one extremity near some small iron nails. Notice that they cling to it only as long as the current is flowing. Replace the bar with one of harder iron and repeat, noticing results. Finally use a steel bar in place of the iron and compare results with those obtained with the other bars (T. 381 to 385).

EXPERIMENT 81.—Float the bar of magnetized steel upon a cork, pass over and parallel to it a copper wire connected to your voltaic cell so that you can cause a current to pass through it. Is there any action manifested between the “live” wire and the magnet when they are not in contact? If so, to what is it due and what will you call the force? Now pass the current beneath and parallel to the needle and on closing the circuit notice in what manner the deflection varies from that in the first part of the experiment. What would be the effect of changing the direction of the current in the wire?

What two ways of reversing a deflection have you discovered? (T. 195, 196, 197).

EXPERIMENT 82.—Modify the last experiment by floating your galvanometer so that its coil stands at right angles to its needle, which will be the case when the needle points to  $90^\circ$  on the scale. Pass the wire over and parallel to the needle. On completing the circuit notice that the needle behaves as did the bar in the last experiment.

EXPERIMENT 83.—Having the galvanometer as in the last experiment, wind a wire once around so that the needle shall lie within the coil and observe whether the deflection is increased. Increase the turns of the wire and observe whether the deflection is increased with each additional turn (T. 200). Use insulated wire in this experiment.

EXPERIMENT 84.—With your insulated wire form an oblong coil  $2 \times \frac{1}{2}$  inches made of six turns. Connect its terminals with the wires from your voltaic cell. Hold the coil just above and parallel to the needle of the galvanometer. When the current is sent through the coil compare the deflection produced with that in the previous experiment using the same number of turns of wire. How can you explain the result? The strength of current in the two cases should be exactly equal.

EXPERIMENT 85.—Place the galvanometer so that the needle shall come to rest at  $90^\circ$ . Now send the current from a bichromate cell through the coil connected with the B terminals and then without making other changes reverse the direction of the current passing through the instrument. Explain the action of the needle in the two cases (T. 196).

## INDUCTION CURRENT INSTRUMENTS.

(T. 228, 229, 230).

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The induction coil is an instrument designed to transform an electric current of a low electro-motive force to one of equivalent energy but having a relatively high electro-motive force.

There are three quite distinct classes of induction coils differing in construction according to the intensity of current desired and in the methods of regulating and controlling them.

1. The first type is a very large coil consisting of a primary of very heavy wire designed to carry strong currents and a secondary coil consisting of thousands of turns of very fine wire very carefully insulated in which currents having thousands and even millions of volts of electro-motive force are generated. The current from this class of coil is comparable in intensity to that of the static machine. They are used in various kinds of scientific research and more recently they have been much employed to illuminate Crookes tubes for the purpose of producing Röntgen rays. Some of the larger of these coils have furnished sparks as much as forty-two inches in length.

2. To this class belong the coils used in physiological research. They give only a short spark but admit of a wide range of adjustment for modifying the character of the current. They are constructed so as to permit the secondary coil to be moved over the primary. They are usually spoken of as Dubois-Reymond coils.

3. To this class belong all coils used in therapeutical

work and spoken of as medical induction coils. The current is practically the same as that produced by those of the second class except that the former do not as a rule admit of so wide a range and gradual change in the strength and character of the current. Coils of this form are often enclosed in a neat case containing a small battery, conducting cords, electrodes, etc., and constitute a convenient portable instrument for the physician's use.

#### THE SIMPLE LABORATORY INDUCTION COIL.

This instrument consists of a primary coil only, the secondary coil being absent. It has sufficient binding posts to attach the battery to it and electrodes are furnished through which the induced current can be utilized. The parts are simple and plainly visible in order that the student may become familiar with its construction and with the principles involved in its operation. The description of the physician's induction coil which follows includes all that need be said regarding the primary coil and its currents.

EXPERIMENT 86. — Attach a 4 volt battery to the simple coil and adjust the parts so that it shall be properly excited. Study the mechanism and working principles of the automatic interrupter. The following are some of the points to which the student should give his attention:

1. Determine the various points for attaching electrodes for applying the induced current.
2. Determine the *time of flow* and the *direction* of the induced current, *i. e.*, whether it flows at the "make" or "break" of the battery current. This is best done by slowly moving the vibrator backward and forward by hand and passing the current thus induced through the tongue.
3. Determine how the soft iron core becomes mag-

netized by the passage of the battery current. From the principles of electro-magnetic induction what is the direction (compared to that of the battery current) of the induced E. M. F. when the core is becoming magnetized and when it loses its magnetic lines of force?

4. What do you think of the relative rates with which the core takes up and loses its magnetic lines of force? What is the effect on the E. M. F. of the primary induced current of increasing the strength of the battery current through the coil?

EXPERIMENT 87.—Test for the effect of moving the brass tube with respect to the iron core upon the E. M. F. of the primary induced current. What is the effect where you employ a tube with a slit along its entire length? Try the effect of enclosing the primary coil in a cylinder of metal and what results when the circuit in this cylinder is broken? What is your explanation of the results of the above observation?

EXPERIMENT 88.—Examine the electric bell and notice the general similarity of its construction to that of the interrupter of the coil. Notice the spark produced by the extra current. Does it correspond to the primary induced current of the coil? At what points would you attach electrodes to the bell in order to send the current through a patient?

## THE PHYSICIAN'S INDUCTION COIL.

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To rightly understand the therapeutic capacities of the faradic battery or physician's induction coil it is necessary to start with a clear conception of the mechanism by which the various currents derived from this apparatus are produced.

The analysis of one of the simpler forms of induction coil, such as is commonly employed by physicians will best serve this purpose as it contains all the essential elements entering into this form of apparatus. The more elaborately constructed coils are but attempts to perfect the working of one or more of the parts of which these simpler or cheaper coils are composed.

The induction coil apparatus used for therapeutic purposes must have—

A primary battery, or other original source of current,

A primary coil,

A temporary magnet,

An interrupter, or circuit-breaking device,

A secondary coil,

Some means for varying the amount of current induced in either coil.

Separate consideration will be given to each of these parts.

**The Primary Battery.**—In the ordinary portable faradic battery one or two wet or dry cells furnish the current which excites the induced currents in the coils. The number and electro-motive force of these cells must be proportionate to the resistance to be met with in the coil circuits. When wet cells are used they are commonly

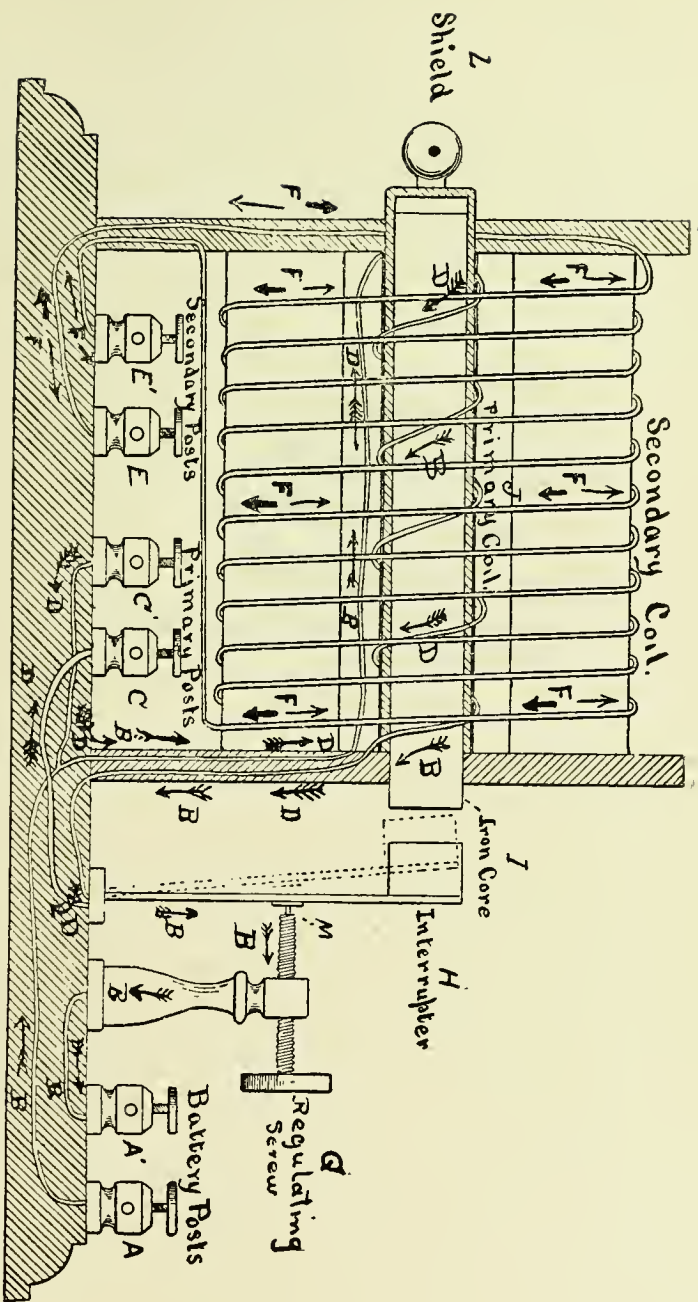
either the bichromate or ammonium chloride cells. The electro-motive force of the former (1.9) is about one-fourth higher than the latter (1.4), neither do they polarize so quickly and therefore maintain a more constant current. The dry cells are more convenient because of being dry, but they cannot be renewed by the operator but must, when exhausted, be replaced by new ones. The composition entering into the various dry cells is a trade secret, but those of larger size usually have zinc and carbon elements with a paste containing ammonium chloride as an excitant. The chloride of silver dry cell is the most convenient because of its small size—but its electro-motive force (.9) is less than that of other forms of dry cells. It requires from two to three volts pressure to properly energize the ordinary induction coil apparatus, and a dynamo current can be used to furnish this current quite as well as a primary battery, but for portable batteries this source of current for exciting the coils cannot be utilized. With coils of greater resistance more electro-motive force is needed in the circuit from which the primary energy is obtained, and in case primary battery cells are used to supply the current the number must be sufficient to meet the requirements of increased resistance. So it happens that in certain forms of induction apparatus recently put upon the market, in which the secondary coil contains a great many turns of very fine wire, four or more primary battery cells are needed to properly energize the coils.

**The Primary Coil.**—The main purpose of the primary coil is to furnish a path for the battery current and to interrupt and transform that current in such a manner as to create induced currents in a secondary coil which is either wholly or but partially within its field of

influence. To accomplish this purpose the primary coil need be made of but few turns of a comparatively coarse wire; the main object being to offer but little resistance to the primary battery circuit. Our laboratory experimental induction coils contain three turns of number 19 wire in the primary coil, the outside diameter of the coil being 2 centimeters and its length 10 centimeters. There is, as we shall presently see, a current possessing peculiar physical properties induced in this primary coil, which is utilized for therapeutic purposes and called the **primary current**. For the purpose of giving a different quality to this primary current some manufacturers have increased the number of turns of the primary coil and used wire of different sizes. The battery current which traverses the primary coil has for a part of its course a vibrator spring, Fig. 35, and a set screw and post which form very essential elements in the action of the induction coil apparatus as will be seen later.

**A Temporary Magnet.**—A soft iron bar or a bundle of soft iron wires capable of being readily magnetized by the passage of the battery current along the primary coil and again promptly losing its magnetism as this battery current is interrupted, is the part of the induction coil apparatus upon which its action chiefly depends.

The main purpose of the temporary magnet is to break the battery circuit and so interrupt the flow of current from the battery through the primary coil. This the temporary magnet does the instant it becomes magnetized through the influence of the current passing in the primary coil which is wound about it. By its magnetic force it attracts the iron head on the vibrator spring or interrupter, Fig. 35, and draws away the spring from the point of the adjusting screw (G) and so leaves a gap (M) in the



Working Diagram. Physicians Induction Coil

battery circuit. This stops the flow of the battery current in the primary coil. The soft iron core then loses its magnetism and releases the head of the vibrator spring which flies back and is again in contact with the point of the adjusting screw. A second advantage gained by the temporary magnet, if placed, as it is in many of the simple forms of induction apparatus within the turns of the primary coil, is an augmenting of the inductive effect

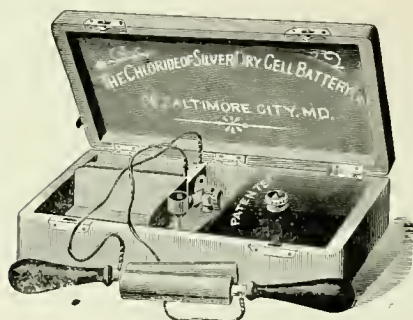


Fig. 26. Faradé Coil with Dry Cells.

on the coils by reason of the magnetic lines of force emanating from the magnet and cutting the turns of wire in the primary and secondary coils. In some of the Du-bois-Reymond forms of induction coil the temporary magnet is used only to interrupt the circuit of the battery current and is placed at a distance from the primary and secondary coils and so this augmenting inducing action upon them is lost.

**The Circuit-breaker or Interrupter.**—The current that flows from the battery through the primary coil must be broken or interrupted at intervals, since it is by the change of potential in the circuit that is thus produced that the induced currents in the coils are created. The range of frequency of such interruptions is determined by the kind of device that is used for producing them. In the ordinary coils the interruptions are effected by a spring at the extremity of which is an iron head (H), Fig. 35. This bit of iron is alternately attracted to and released from the temporary magnet. The rapidity with which interruptions

can be made by the mechanism varies greatly in different instruments. It depends upon the strength of the magnetic flux, the readiness with which the magnet takes on and gives up its magnetism, the length of the spring and its elasticity. Seldom are any two instruments of the same pattern alike in all of these particulars. The maximum of interruptions that can be brought about in our ordinary laboratory coils averages 60 per second, and these are a fair sample of the induction coils in general use. By greater attention to details in the construction of this and other parts of the induction coil, as in the use of longer and more nicely adjustable springs, and the use of a quality of iron in the temporary magnet that will insure the greatest promptness in response to the inductive influence, the rapidity of interruptions by this method can be considerably increased. But we have yet failed to find an instrument with a spring vibrator in which the number of interruptions can be made to reach 200 per second. The number of interruptions in an induction coil current is one of the important elements in producing physiological and therapeutic effects, since the greater their frequency the more the sharp and irritating quality of the current is reduced, and the more soothing it is in its influence. Numerous attempts have been made to secure more rapid and uniform interruptions by other arrangements than that of the spring vibrator, but so far the devices have been either too complex or expensive to create much demand for them. The Englemann segmented rotary interrupter, run by an electric motor, is capable of greatly increasing the number of interruptions and with perfect uniformity, but its cost places it beyond the reach of the majority of those using induction coils.

**The Secondary Coil.**—The secondary coil is the induction coil proper, and the current derived from it can be caused to vary considerably in strength and quality at



Fig. 37. Form of Induction Coil, used in this Laboratory.

the will of the operator. This coil is always made of finer wire than that used in the primary coil. It usually has a much greater number of turns also and the length of the wire is, of course, proportionately increased. In our laboratory experimental coils the secondary is wound

with number 31 wire and has 3 layers, the length of wire used being about 180 feet, the resistance of which is about 35 ohms. Most secondary coils for physicians' use are now made of still finer wire. Number 36 is preferred by many, and the number of layers is as many as eight or ten or even more.

The finer the wire the greater the number of turns made in each layer, and as each additional turn of wire adds one to the frequency with which the lines of magnetic force, emanating from the primary coil and the temporary magnet, cut the secondary coil, and so increase the electromotive force of the secondary coil current, a great number of turns in the secondary coil is by some thought desirable. But there is a limit to the advantages to be gained by lengthening the wire and increasing the number of turns in the secondary coil. The resistance of the amount of

wire used and of the self induction created in the coil may prove too much for the primary battery current to overcome and the resulting secondary induced current will be very feeble.

Much of the efficiency of the faradic or induction coil apparatus depends upon the nature of the secondary coil current and as a different quality is required in this current for different therapeutic purposes, some manufacturers provide several secondary coils with different sizes and turns of wire. Others make a continuous winding of the one size of wire but make this of considerable length, and then tap the wire at intervals so that the current from all or only a part of the coil can be used as desired. The nature of this secondary current as compared with the primary induced current will be considered further on.

**Current Regulation.**—Every induction coil apparatus is provided with some means for increasing or decreasing the strength of the currents derived from it. This is done by modifying the strength of the magnetic field that induces currents in the coils. One of two ways is used to do this. The coils are arranged, in the one case, to move one over the other as in the Dubois-Reymond type of coil, which is the form usually employed by physiologists for their experimental work, and which produces very fine and uniform gradations in the amount of current. Or a metal shield of brass is made to slip over the temporary magnet placed in the axis of the coils which shield, when in place, attracts to itself the lines of magnetic force emanating from the magnet and prevents them from cutting across the turns of this coil. As the shield is removed the lines of magnetic force are released and thus induce currents in the coils in proportion to the extent to

which the magnet is uncovered. A crude method of measuring the strength of induction coil currents is to attach an inch or meter scale to the apparatus so as to measure the position of this shield at any moment or in the other case the extent to which one coil covers the other. All the better instruments are provided with such a scale.

#### NATURE OF THE INDUCTION COIL CURRENTS.

We must now, in order to judge of their therapeutic applications, study the modalities of the electric currents that are derived from the physician's induction coil. When this apparatus is in action, it is capable of generating three distinct currents.

The battery current,

The primary induced current,

The secondary induced current.

**The Battery Current.**—No attempt is made to use the battery current in the induction coil apparatus for therapeutic purposes. Its function is to supply an electromotive force in such manner as to create magnetic lines of force in the temporary magnet and exercise an inductive influence upon the coils. In order to effect this so as to secure a succession of induction current impulses, the battery current must be interrupted with more or less frequency, as it is only by varying the number of lines of force that cut across the coils that an induced current is created in them. The "make" and "break" of the battery current, which is effected by the interrupter, is an indispensable feature, therefore, in the induction coil apparatus. And the frequency with which these interruptions in the battery current take place determines, in a great measure, the nature and physiological and thera-

peutic effects of the induced currents which follow. The battery current should be strong enough to saturate the temporary magnet with a magnetic flux and to successfully withstand the opposing electro-motive force which is created by self-induction in the primary and secondary coils when their circuits are closed. The larger the temporary magnet and the greater the resistance and number of turns in the primary and secondary coils, the greater will need to be the electro-motive force of the

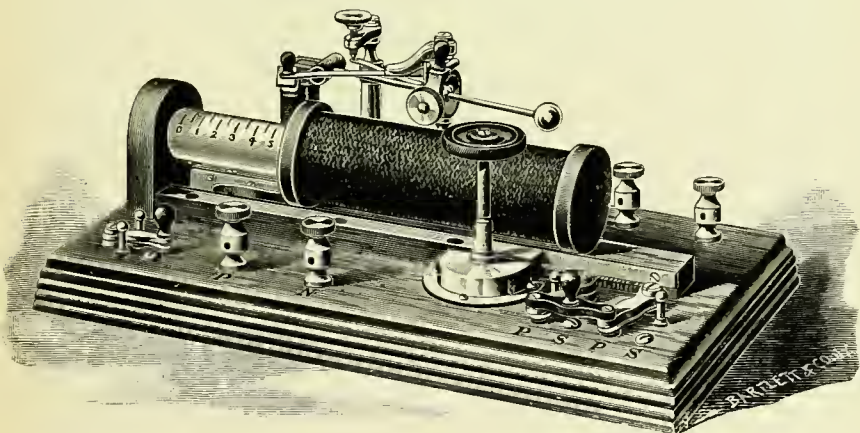


Fig. 38. Induction Coil with changeable Vibrator.

primary battery used for furnishing this battery current. The battery current (ABBBA') in Fig. 35, is, of course, a direct or galvanic current, that is a uni-directional current, but it is interrupted or broken as often as the spring (H) is carried away from the contact (M). The E.M.F. of this current depends upon the kind and number of cells used, and the amount of current depends upon the resistance in the circuit. The quantity of current may vary, therefore, from half an ampere to several amperes, according to the make-up of the apparatus.

**The Primary Induced Current.**—At the moment the magnetic lines of force which emanate from the temporary magnet as a result of the influence of the battery current begin to cut the turns of the primary coil, an electro-motive force is generated by them in the primary coil, which is opposed to the flow of the battery current and decreases it. When the battery current is interrupted by the breaking of the circuit at the spring vibrator, the inductive influence of this current on the temporary magnet ceases, and there is a sudden withdrawal of the magnetic lines of force which came from this source.

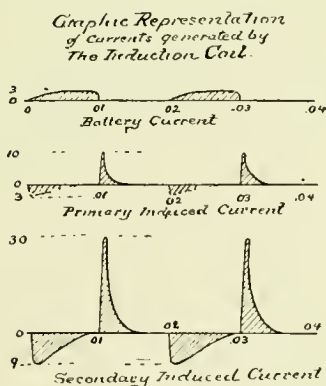
This sudden loss of potential creates an induced current in the primary coil which has the same direction as the battery current, but as the battery circuit is open between the contact point and the spring, this current can only traverse that circuit by leaping the air-gap, which it does at times and causes the spark which is seen at this point when the instrument is in action. If another circuit is provided for this current that is induced in the primary coil at the "break" of the battery current, then this induced current at the "break" can be utilized in therapeutic work. And this is the origin of the current derived from the medical induction coil that goes by the name of **primary current**. It is a unidirectional current, (Fig. 39) but interrupted with a frequency corresponding to the movements of the vibrator. It has the same direction as the battery current, but differs from it in having less of quantity but higher electro-motive force. Both its strength and electro-motive force can be varied by moving the shield covering the core, or by changing the position of the core itself, if this is made movable.

The primary induced current has in a feeble way the properties of a direct or galvanic current. It is both elec-

trolytic and cataphoric to a slight degree, but its chief action upon the living organism is as an excitant to contractile tissue and to sensory nerves by reason of the interruptions which cause a sudden variation in potential. The suddenness of this change in electro-motive force makes this current a powerful stimulant for exciting muscular contractions and for arousing the action of sensory nerves.

**The Secondary Induced Current.**—The secondary

coil winding (FFFF)(Fig. 35) is entirely distinct from the primary and has its separate terminals at the binding-posts (EE'). In some forms of induction coils the secondary coil can be removed from the instrument, and these instruments are supplied with several secondary coils differing in size and length of wire and in the number of turns. There are



induced currents generated in the secondary coil both at the “make” and “break” of the battery current. The inductive effect on the turns of the secondary coil at the “make” of the battery current is due to the lines of force from the magnet cutting across them. This current is comparatively slow in its increase to the highest potential because of the somewhat gradual development of these lines of force. The induced current at the “break” on the contrary because of the sudden withdrawal of these magnetic lines of force, is more promptly developed to its greatest intensity and, of course, in the opposite direction from the current induced at the “make.” The secondary coil current

then is a to and fro, or alternating current (Fig. 39) with the "break" a little greater in intensity but shorter in duration than the "make" current, while the frequency of the alternations or the number of periods depends upon the action of the vibrator or interrupter. The electro-motive force in this current is determined by the number of turns in the coil that are cut by the magnetic lines of force, and the quantity of current is determined by the resistance offered to its flow and the strength of the magnetic flux which induces it. The electro-motive force, when a fine wire of many turns is used in the secondary coil, is much higher than that of the primary induced current, while the amount of current is correspondingly much less.

The alternating character of this current prevents it from being either electrolytic or cataphoric, while its physiological effects depend very much upon the structure of the coil and the frequency of the alternations. If the alternations are very frequent and the coil composed of many turns of fine wire, the resulting current, though interrupted, begins to resemble in physical properties a sinusoidal current. The approaches to and departures from the highest and lowest potential in each period is, by this construction, made more gradual and the effect physiologically is stimulating and yet not irritating. Its effect, therefore, is tonic and at the same time sedative on both motor and sensory nerves.

#### EXPERIMENTS WITH THE MEDICAL INDUCTION COIL.

Before proceeding with the following experiments demonstrate the induction coil to the instructor in charge of the laboratory.

EXPERIMENT 89.—What currents does the physician's induction coil furnish? Test the effect of removing the

draw-tube. What are the effects of increasing the battery power? Pass the current through the body from arm to arm. Bare the fore-arm and with pointed electrodes covered with absorbent cotton and moistened with a saline solution and with the other flat electrode on the back of the neck, cause contractions of each separate muscle of the fore-arm with the weakest primary and then with the weakest secondary current that will cause a contraction. The pointed electrode should be placed over the point of entrance of the nerve supplying the muscle.

EXPERIMENT 90.—Determine by moving the vibrator slowly back and forth whether the secondary current flows both at the “make” and “break” of the battery current. Is there any difference in the direction and intensity of the impulses?

EXPERIMENT 91.—Send the secondary current through the galvanometer which is considerably removed from the coil, and notice if it causes any deflection of the needle. Move the interrupter slowly by hand and see if there is any difference. Determine by experiment whether either the primary or secondary induced currents are capable of effecting electrolysis.

EXPERIMENT 92.—Using the large dissected coil, study the effects of removing the secondary coil from the primary and also the effect of varying the number of wires which make up the coil.

EXPERIMENT 93.—With the skeleton coil and a telephone receiver notice the induction effect between two simple coils. Observe the sounds on making and breaking the circuit slowly and the effect of removing the core.

## THE MAGNETO-ELECTRIC MACHINE.

(T. 222, 223, 224, 461.)

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The magneto-electric machine is a current generator which was at one time quite generally used in therapeutics. The form commonly employed consists of two coils of fine wire, each having a soft iron core and mounted in such a manner that they can be rotated near a permanent horse-shoe magnet. In this manner the number of magnetic lines of force passing through the two cores is made to change continually, their polarity also changing, and corresponding currents are set up in the coils according to the principles discovered by Faraday. The two coils are so joined that the E. M. F. generated in each reinforces the other. In machines not employing a commutator the current is alternating in nature, each revolution of the coils corresponding to a single impulse in each direction. The rate of alternation is considerably slower than in the secondary induction coil current and in the sinusoidal current. The variations of E. M. F. are not so abrupt as in the induction coil although some types are so constructed as to cause sudden variations of the E. M. F. The current from the magneto-electric generator may be represented graphically very much like the sinusoidal current except that the undulations are much less regular. In some machines of this kind the current is made to flow all in one direction by means of a commutator. The current then resembles the direct or galvanic current except that it is irregular both as to amount of current and electro-motive force.

EXPERIMENT 94.—Examine the various forms of magneto-electric generators in the laboratory and be prepared to demonstrate any of them to the instructor. Take the current from one of them through your body from hand to hand and compare the sensation to that produced by the direct current (galvanic) and the induced current from the induction coil (Faradic). Attempt to electrolyze a solution of copper sulphate with it. Determine the nature of the current by passing it through the long coil of your galvanometer. How can the current be regulated in strength? Is the current generated sufficient to heat a cautery wire? Can it be used for cataphoric or electrolytic purposes on the body?

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### THE SINUSOIDAL CURRENT.

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By a sinusoidal current is meant an alternating induced current in which not only the rise and fall of potential or electro-motive force of positive direction is immediately succeeded, without break, by an exactly corresponding rise and fall of potential of negative direction, but one in which this rise and fall in both directions would, if shown with accuracy in diagram, describe a sine curve. The accompanying illustration, Fig. 40, taken from Prof. H. S. Carhart's work on Elementary Physics, with the permission of the author, well illustrates this form of curve.

Mathematically considered this curve may be defined as one resulting from two rectilinear motions at right angles to each other; the one being a uniform rectilinear, the other a simple harmonic motion. This last named motion is one well illustrated by the common pendulum, which moves most rapidly at the middle of its swing,

decreasing in rapidity as it approaches the ends. The figure represents diagrammatically a combination of these two motions. The equal spaces made by the vertical lines at the right represent the progress of the uniform rectilinear movement from left to right, while the spaces between the horizontal lines represent the simple harmonic movement or sine displacements. These spaces on the vertical lines are obtained by dividing the circle at the left into 16 equal arcs and drawing horizontal lines through the points marking their boundaries, as 1, 2, 3, etc. Now if we assume that this circle is made to revolve at right angles

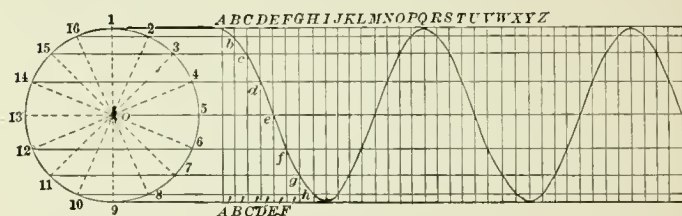


Fig. 40.

to the plane of the paper with the line *o, 5, e*, for its axis, one revolution of the circle will correspond to a complete vibration of a pendulum, and if, while revolving, the circle moves from left to right at a uniform rate along the axis *o, 5, e*, then the displacement of any point upon the margin of the circle from the middle line is proportioned to the sine of the angle of rotation on the circle. Thus if we take the point 5 and rotate it through the arc 5, 6, the vertical displacement of the point 5 will be the sine of the angle of rotation 5, *o*, 6. Again the vertical displacement from 5 to 7 is the sine of the angle 5, *o*, 7. It will be seen that these sines correspond to vertical distances between the horizontal lines at the right of the

circle and that the diagonal lines in the parallelograms are but the resultant of these two movements of the circle.

The sine curve can be platted by completing these diagonal lines through one entire revolution of the circle.

The current derived from the secondary circuit of an induction coil, Fig. 35, has been shown to be alternating, but the positive and negative alternations differ considerably in electro-motive force and the gradations from zero to the greatest difference of potential in either direction are not regular and uniform but quite the contrary. Moreover, the secondary current of the induction coil is interrupted, the time interval occupied by the interruptions exceeding considerably that consumed by the passage of the current. In these respects the secondary current of the induction coil differs from a sinusoidal alternating current in its physical properties, and these physical differences have of necessity a corresponding difference in physiological and therapeutic effects. By increasing the length and number of turns of the secondary coil and increasing the rapidity of the vibrations of the interrupter the current derived from the secondary coil of the induction apparatus is made to approach more nearly in physical and physiological properties the sinusoidal current as at present used.

The magneto-electric apparatus, which has been spoken of and which some years ago was not infrequently seen in physicians' offices, likewise creates an alternating current. But the alternating current generated by this little machine, while it shows no interruptions when the coils are revolving, is yet quite irregular as compared with a sinusoidal current, since the lines of magnetic force emanating from the poles of the magnet cut the turns of wire in the coils as they revolve, in such manner

as to create no uniformity in the increase and decrease of the induced currents. It is, however, only in this feature of construction that this well-known magneto-electric machine differs from several of the sinusoidal machines that are now being manufactured for therapeutic work. In these latter the attempt is made, with more or less success, to secure such uniformity in the increase and decrease of the number of the magnetic lines of force that cut the coils as they revolve, that the electro-motive force generated will describe the sine curve. This desirable result is the more nearly attained according as the permanent or electro-magnets used are so shaped as to furnish to the coils a strictly uniform gradation in the strength of the magnetic field as they enter and leave it. Although the modern apparatus shows great progress in skill and workmanship yet it is quite probable that no so-called sinusoidal machine has yet been constructed that describes accurately in its action the sine curve.

The alternating current dynamos now used so extensively for lighting incandescent lamps furnish a current which is roughly sinusoidal and can be utilized by physicians who have access to it and have some form of controller suitable for modifying its strength and voltage. As the speed of these dynamos, while in action, is quite uniform, the number of alternations do not vary much and the frequency is often much less than is wanted in therapeutic work, being often but 124 alternations per second. It is convenient and oftentimes quite desirable to have an apparatus for the generation of a sinusoidal current so arranged that the operator can vary the frequency of alternations, the electro-motive force and the current at will, and this is possible with some of the machines now manufactured, two forms of which will be illustrated and described.

PHYSIOLOGY AND THERAPEUTICS OF THE SINUSOIDAL  
CURRENT.

There are several physical peculiarities possessed by the sinusoidal current which help to make its action on the body different from that of other forms of current. As has been seen from the foregoing description the increase and decrease of potential in this form of current is gradual and uniform and never abrupt nor sudden in its change. It is no doubt to this feature of the current that its peculiar action on the sensory and motor nerves is mainly due. The sensory and motor mechanism of the body is capable of adjusting itself to a considerable range of difference in external conditions without serious disturbance or discomfort, provided the change is not too sudden or violent. Even though there may be many periods of alternation of current per second and the electro-motive force be quite high, yet the action of nerve and muscle is still capable of responding to such variations without disagreeable reaction provided the change in strength is gradual. The number of alternations per second, the degree of electro-motive force and the quantity of current are, no doubt, each important factors in determining the physiological and therapeutic effects of this current, but these are not so peculiar to it as is this feature of uniformity in change. The effect of this special feature of the sinusoidal current is to lessen the disagreeable effects of electric excitations both on the sensory and motor mechanism. The same amount of stimulation to muscular action can be aroused as by any other equally powerful means, without the accompanying pain and consequently without the shrinking and apprehensiveness on the part of the patient which other forms of excitation arouse. In this lies the chief advantage of

the sinusoidal current over the current derived from the secondary induction coil, while in many other respects these currents are similar in action.

For exciting to vigorous action muscular tissue, therefore, whether it be the voluntary or involuntary variety of muscle, the sinusoidal is the current *par excellence*. Such frequency of alternations can be used as will adapt the excitation to the requirements of the muscular structure. The comparative painlessness of the applications permits the use of greater electro-motive force and more current than can be used either from the induction coil or the primary battery, so that physiological action of the muscles is more thoroughly aroused than by the use of either of these other forms. The more nearly the curve of current conforms to the sinusoidal the less will there be of effects resulting from polar action. Electrolysis and cataphoresis will be avoided and the changes brought about in the tissues to which the current is applied will be mainly those which are normal to their function; the effect of the current being to arouse that function to greater activity. When we consider how many of the normal processes of the body, such as assimilation, circulation, secretion, excretion, locomotion, etc., depend directly upon muscular tone and vigor it will be seen at a glance what a wide range of therapeutic application is possessed by this form of current in the field of muscular excitation alone. It has been highly spoken of by many competent electro-therapeutists as a means of improving the nutrition and growth of muscular tissue whenever it is failing from lack of proper excitation.

General muscular weakness, local paralysis or paresis, lack of intestinal peristalsis, vaginal and rectal prolapsus, due in whole or in part to lack of muscular tone, and

vaso-motor debility are some of the conditions in which this form of current has proved especially beneficial.

It has been said that the sinusoidal current is remarkable for the little amount of sensory excitation it causes, and so permits powerful muscular contractions without discomfort. Further than this it serves to allay pain. It is as much if not more serviceable in this way than is the current derived from the secondary induction coil of many turns. Apostoli and others have borne strong testimony to the fact that the greatest success they have attained with this form of current has been in allaying the pains that occur in connection with the pelvic organs. The pains caused by uterine inflammation, pelvic cellulitis, ovaritis, salpingitis and congestion are quickly allayed by it. Neuralgic pains are relieved and those of spinal irritation. Marked effects on tissue metabolism have been noticed also as indicated by increased consumption of oxygen and more rapid elimination of carbon dioxide. These effects are in all probability secondary to and dependent upon the increased muscular activity and analgesic influence of the current.

#### THE MC INTOSH SINUSOIDAL APPARATUS.

This instrument, Fig. 41, is one result of the most recent attempts by manufacturers to provide a source of sinusoidal current for therapeutic work. It consists of a small motor wound for the 110 direct current and has connected with it a special rheostat for controlling its speed. The shaft of the motor is extended and carries on this extension the armature of the sinusoidal machine, thus making a very convenient and compact arrangement, doing away with belts and pulleys. The armature carrying the winding of the coils of wire in which the induced

sinusoidal currents are generated revolves between the poles of a group of three powerful permanent magnets, the pole pieces of which are so shaped as to secure a uniform gradation in the lines of force which cut across the revolving coils on the armature. From the coils the current is conveyed to binding posts on the base of the instrument, but before the current reaches the binding posts a graphite rheostat is interposed regulating the

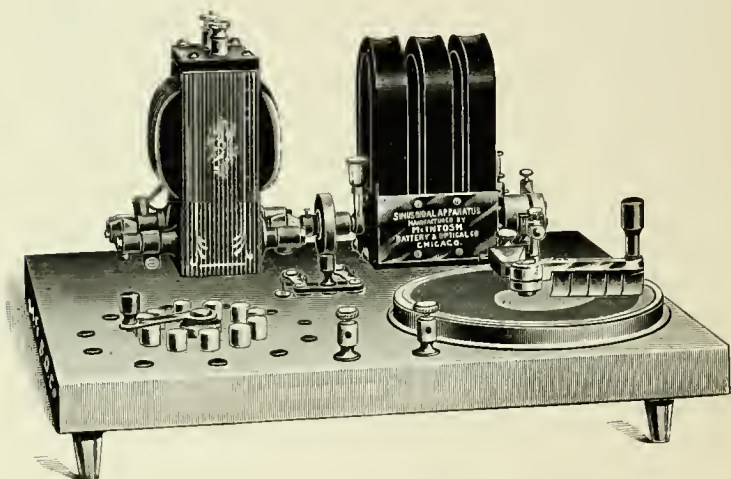


Fig. 41.

strength of the current. This arrangement makes the apparatus complete. It is only necessary to connect the binding posts on the top of the motor with a suitable direct current circuit such as the Edison incandescent light circuit, or a street car or power dynamo circuit of higher voltage, provided sufficient lamp resistance is introduced so as to reduce the potential, and then complete the patient's circuit by attaching electrodes to the binding posts on the base. The rapidity of alternations and consequently the voltage is readily modified by the

rheostat in the motor circuit while the strength of current can be graduated independently by means of the rheostat in the patient's circuit. Two additional brushes are in contact with a commutator on the outer end of the armature shaft and these serve to deliver the current generated as a current in one direction, instead of an alternating one, when this is desired. The direct current so produced can be thrown into the patient's circuit by a proper movement of a switch which is provided on the base. By connecting the motor of this instrument with a power circuit in this laboratory, the current supplied to the motor registering by a Weston meter 120 volts, we were able to run the armature shaft at the speed of 5280 revolutions per minute when all resistance was off the motor circuit. The number of alternations would of course be twice this, or 10560 per minute; or 176 per second. By diminishing the speed of the motor any less number of alternations per second could be obtained. The strength of current could be modified from that which was barely perceptible up to that which would produce the most powerful muscular contractions, and yet at no time was the sensation produced, either in the integument or muscles, disagreeable or painful as is so often the case with the current from the faradic coils. The electro-motive force that is developed in the patient's circuit depends upon the speed with which the armature is made to revolve. At the highest speed attainable the Weston alternating voltmeter registered 110 volts and at the slowest speed, 33 volts. If a lower electro-motive force with great frequency of alternations is desired this could be readily accomplished by having a less number of turns in the armature winding.

The direct or galvanic current that is furnished by this instrument is of course not uniform in potential but varies

in intensity at each revolution of the armature. With this also the speed determines the amount of current. The milliampere-meter showed this current to be 10 milliamperes at high speed, and when a patient was between the electrodes and the direct current was carried up to the limit of tolerance the amount of current was between three and four milliamperes. Electrolytic work was readily done by the direct current but the comparatively high electro-motive force that was required to get sufficient current for electrolysis might in some instances in actual practice prove disagreeable to a patient, and the direct current derived from this apparatus cannot be made to take the place entirely of a galvanic battery or other sources of direct current.

#### THE KENNELLY SINUSOIDAL MACHINE.

This machine (Fig. 42) bears a striking resemblance to the ordinary multi-polar alternating current dynamo, but on closer examination it will be found that both the primary (exciting) and the secondary windings are placed upon the field frame. The field frame is of laminated iron supported by castings and has twelve poles; on each pole is a spool with two windings of wire. The inner has eight layers of fine wire and the outer two layers of coarse wire. All the coarse wire windings are connected in series in such a way that the magnetic polarity produced shall be alternately north seeking and south seeking, when a direct current is sent through this circuit.

The armature is composed of several discs of sheet iron firmly fastened together, having slots and projections as will be seen from the figure. This armature is just large enough to rotate freely within the concentrically arranged pole pieces. Bearing in mind the relation of the

secondary coil to the pole, it is evident that anything causing an increase or decrease of magnetic lines of force through the pole, *i. e.*, any variation of the magnetic flux, will induce a current of electricity in the secondary. The E. M. F. of this induced current will depend upon the number of turns of wire and the rate of increase or decrease of the magnetic flux. In this machine the direct

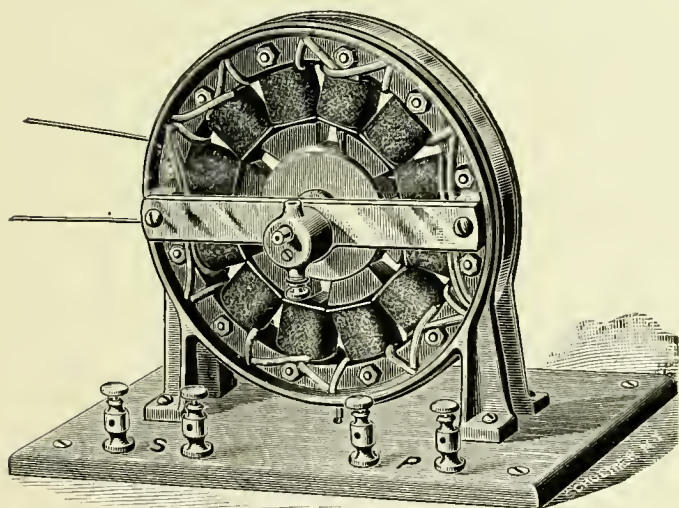


Fig. 42.

current passing through the coarse wire windings constitutes the magneto-motive force; this remaining constant, the magnetic flux will vary inversely with the reluctance, *i. e.*, the “magnetic resistance.”

The law of the magnetic circuit may be stated as follows:

$$\text{magnetic flux} = \frac{\text{magneto-motive force}}{\text{reluctance.}}$$

The reluctance of air being very great as compared with that of iron it follows that the magnetic flux in any pole

will be suddenly increased when the air-gap or slot opposite that pole is displaced by the iron projection of the rotating armature, thus inducing a current in one direction and the next instant when the wire projection is passing and the next slot is coming opposite the pole there will be a decrease of magnetic flux and a corresponding current in the opposite direction.

The slots and projections of the armature are so proportioned that the graphic representation of these alternations of the current closely approximate the true sine curve, thus giving the so-called sinusoidal current. Twenty-four alternations or twelve complete periods occur at each revolution of the armature; a speed of 80 revolutions can be attained and will therefore give 1920 alternations per second or a frequency of 960.

The E. M. F. of the secondary current varies with the amount of current flowing in the primary, *i. e.*, with the magneto-motive force. This fact offers a convenient method for regulating the voltage of the secondary without varying the speed. The primary current may be derived from primary batteries or from street mains and should be passed through a rheostat so that it may be varied from two amperes to the small fractional part of an ampere.

The E. M. F. when the secondary is open varies directly with the speed and the strength of current in the primary circuit. With one ampere in the latter circuit, the limit of E. M. F. in the secondary is about 50 volts, which is about 70 volts at the top of each wave, the 50 volts representing the average electric pressure. On short circuiting the secondary, the voltage is reduced nearly to zero, but in practice this will not occur except by accident. The E. M. F. of the secondary passing through the body

of a patient will vary with the resistance offered, but since this resistance is always comparatively high the E. M. F. will practically amount to that recorded by a voltmeter in open circuit.

In comparing this machine with others built for the same purpose the following are some of the facts to be considered:

The Kennelly machine requires both a motor for running and some independent source of direct current for exciting the fields. Neither of these are necessarily disadvantages as the physician may possess these accessories, and if he should not they may be procured at a cost probably not exceeding that of those furnished with other machines. Further, as has been shown, the independent exciting current can be so controlled as to vary the E. M. F. of the secondary without affecting the rate of alternations. This is a decided advantage and one not possessed by some other machines which we have examined. Again, it has the very desirable high rate of alternations attained by few others and which can be varied by the motive power employed without materially changing the voltage.

EXPERIMENT 95.—Attach hand electrodes to the various forms of apparatus in the laboratory for generating the sinusoidal current and take the current through the body. Test the effect of varying the speed at which the machines are run and also of varying the action of the other controlling devices. Compare the sensation experienced with that produced by the induction coil currents and also with that generated by the magneto machines. Pay special attention to the physical characteristics of the various alternating currents and to their physiological effects.

## THE INDUCTION TRANSFORMER FOR CAUTERY.

(T. 224, 228.)

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The instrument here described (Fig. 43) is one designed to change the ordinary alternating current used in lighting circuits to a current which is better adapted to meet the conditions found in a cautery circuit. It has been seen

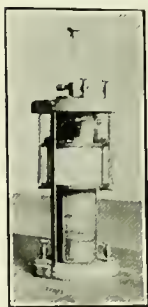


Fig. 43.

that a current in one system is capable of setting up a current in another system near it by induction. This is accomplished by the rapidly changing magnetic field of the primary system which extends to the secondary system. A current is thus set up in the secondary coil which exactly corresponds in the rate of alternation to that in the primary. Except for a certain loss in the transformation, the electro-motive forces of the two systems will be proportional to the number of turns of wire in

each. Further, the strengths of current in the two systems will be so related that the energy ( $C E = E$ ) of the one will equal that of the other. When the secondary coil has fewer turns than the primary the E. M. F. will be reduced and this is called a "step down" transformer.

The conditions required in a current for heating a cautery are such as demand a large current at a low E. M. F., and these conditions are met when the secondary coil is made of few turns of heavy copper wire. The strength of current is nicely regulated by sliding the secondary over the primary coil. By this method the control of the current is so perfect as to render a cautery rheostat in circuit entirely unnecessary.

## HIGH POTENTIAL, HIGH FREQUENCY CURRENTS.

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Currents of high tension and of great frequency of alternations have long been known to the electro-therapeutist who is familiar with the action of the static machine. The discharge which takes place between the prime conductors of such a machine, when they are supplied with Leyden jars or condensers, is at times of this nature. During the small fraction of a second required for such discharge, which may be spoken of as an instantaneous current, the electric polarity changes many thousand times, in oscillations of gradually diminishing amplitude. When the arrangements during a treatment with the static machine in action is such as to make the patient on the insulated stool the terminus of the charge from one of the condensers, and a ball electrode connected to the other condenser is brought sufficiently near the person of the patient to permit a spark to pass, *i. e.*, the direct or indirect treatment by sparks, then, provided the relation of capacity to resistance is just right, the patient is subjected to a current of high frequency and high potential for the instant corresponding to each discharge. Again, the static machine may give rise to high frequency, high potential currents in what has been termed the *static induced circuit*, a current that is obtained in a circuit connecting the outer surfaces or armatures of the Leyden jars or condensers. The patient may be made a part of this circuit and so be subjected to the influence of these high potential, high frequency currents.

But as one of the important features of this peculiar electric modality in its relation to physiological and therapeutic action is the oscillatory character of the discharge, the static machine as it is customarily employed cannot be depended upon with certainty to furnish a discharge of this nature. Whether or not the spark discharge of the static machine is *impulsive* or oscillatory in character depends upon the relation which the capacity of the machine and condensers bears to the inductance and resistance of the circuit, and as certain of these terms vary from time to time, due to atmospheric conditions and manner of application the physical nature of the discharge likewise varies, and therefore the static machine, in the arrangement of its parts as now employed in therapeutics, does not furnish the high potential currents with such invariable regularity in number and frequency of the oscillations as is required for accuracy in scientific observations and comparison of results.

If the output of electric energy from the static machine was stable and uniform the capacity of the condensers could be so adjusted to the resistance and inductance in the circuit as to secure constancy in the oscillatory nature of the discharge from them, but the obstacles to this end have not yet been overcome.

Other sources than the static machine have therefore been sought for and developed for generating high potential, high frequency currents. Tesla, Elihu Thomson and d'Arsonval have each been active in this search, and each in his independent line of investigation has made use of large induction coils as step-up transformers of the original electric energy, which in some instances is derived from alternating dynamos of low frequency and in others from some direct current source, as a dynamo, a primary or

secondary battery. The low frequency of the alternating dynamo must be changed to a high frequency, and the constant or direct current must be broken up into sudden impulses with interruptions in order to furnish the

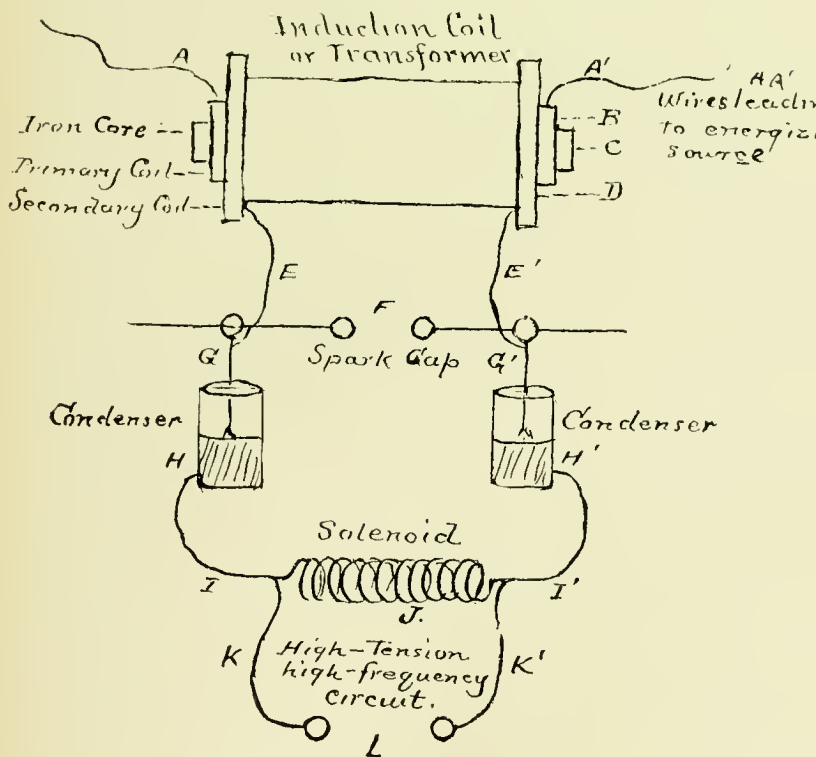


Fig. 44.

proper variations for inducing currents in the windings of the induction coil. These necessities give rise to some peculiarities in mechanism which have been variously constructed by the different inventors. The underlying principles by which the ultimate result is secured are the same

in all. The accompanying diagram (Fig. 44) will illustrate the various steps in the process.

B C D is an induction coil or transformer whose primary coil is energized from some source, preferably an alternating current dynamo. If the energizing current is a direct current source then the primary circuit would need to be supplied with an interrupting device to break the current into periods, such as the spring vibrator attached to the ordinary induction coils or, what is better, a rotating disk driven by a motor and so arranged as to make and break the circuit with great rapidity and suddenness, as in the method devised by d'Arsonval. With the primary coil excited in either manner named, induced currents are created in the secondary coil D, the terminals of which are joined to the internal armatures of two condensers or Leyden jars G G', between which is arranged a spark gap F. The external armatures of the condensers H H' are joined through a solenoid J of copper wire large size and about 20 turns. When this system is in action, at each break or alternation in the primary circuit, the E. M. F. induced in the secondary coil charges the condensers. In proportion to the charge the difference of potential between the armatures increases. When it reaches the limit of the area of the ball terminals and the space separating them at the spark-gap, which may be many thousand volts, a discharge takes place across the air gap and oscillates between the condensers, while the solenoid J is traversed by a current of a frequency corresponding to the frequency of the oscillations. These oscillations are prevented from discharging into the circuit of the secondary coil because of its great self induction. When operating the system by energizing it from an alternating dynamo circuit the charging and discharging of

the condensers is so frequently repeated that an arc is likely to form across the spark gap and so put an end to the oscillatory nature of the discharge. In order to prevent the formation of this arc Tesla and Thomson employed first, a strong magnetic field and later, an air blast at the spark gap.

When we compare the action of this system when energized by the alternating dynamo current, or the interrupted direct current, we find that with the first the inductive effects of the two waves of positive and negative potential are the same, so that when the alternation has a frequency of 124 periods per second as is customary with the ordinary alternating dynamo used for industrial purposes, there will be double the number or 248 single inducing waves each second. With the direct current interrupted a current effective in charging the condenser is induced in the secondary only at the instant of "make," so that to have the same number of useful waves as with the alternating dynamo current, it would be necessary for the interrupter to produce 248 contacts per second.

The currents that traverse the solenoid induced by the discharge of the condensers to the outer armature of which the solenoid is connected are those that are ordinarily utilized for therapeutic purposes. By connecting conductors to each end of the solenoid a circuit can be provided through which these currents can be conveyed. This may be termed the patient's circuit, for it is to the current generated at this point that the patient is, in one or the other manner, subjected.

By an additional device, that is another step-up transformer, these currents may be brought to generate others of still higher tension. These have been termed "currents of second order," and are obtained by having the

solenoid of sufficient diameter to permit of placing within it a glass tube enclosing a coil of fine, well insulated wire, of many turns but a single layer. Currents of such extremely high potential are excited in this inner coil when the solenoid is excited that the glass tube surrounding the coil of fine wire needs to be filled with oil to serve as an insulator. The terminals of this fine wire coil brought out at the extremities of the glass tube through proper stoppers can then be connected up in any manner desired so as to exhibit the nature of these "currents of second order."

Hertz, Tesla and Thomson have each devised a number of beautiful and striking experiments by which to demonstrate the energy possessed by these high frequency and high potential currents. It was early discovered that they failed to excite the animal organism either in the form of sensation or muscular movement, and yet after traversing the body they render lamps and vacuum tubes incandescent, and in many ways exhibit an expenditure of electric energy which if applied to the animal body in one of many other forms would prove instantly destructive.

#### ESSENTIAL PROPERTIES OF HIGH POTENTIAL HIGH FREQUENCY CURRENTS.

As pointed out by Bordier, these currents are distinguished from ordinary alternating currents by three essential properties, which are due to both the great frequency and the high tension.

1st. They cause remarkable inductive effects.

The E. M. F. of induction near an inducing source is equal to the product of the intensity of the current by the frequency. Let us suppose a frequency of 500,000 periods per second and a mean current of 1 ampere. The E. M. F. in one turn would be the same as if a current of 100

amperes with a frequency of 50 should circulate in 10 turns of wire. Thus it is seen that with high frequency the E. M. F. induced in a single turn would be considerable. In a large solenoid the current induced in one turn is sufficient to illuminate by mutual induction a lamp of 8 volts and 1 ampere.

2nd. Currents of high frequency, even though the capacity be small, circulate as well in open as in closed circuits, so that contact with only one pole suffices to give a current

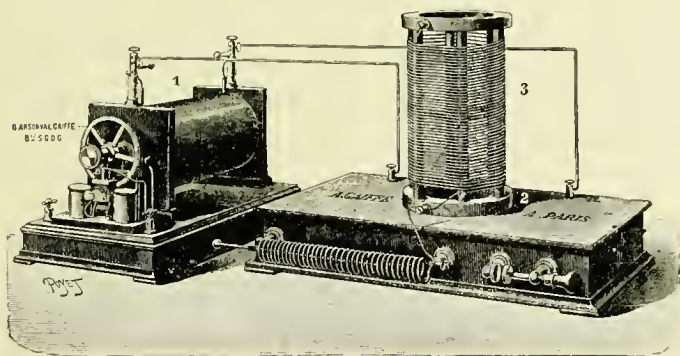


Fig. 45.

In fact, feeble as may be the capacity, the charge and discharge, repeated hundreds of thousands of times per second at a high potential, represent a notable mean current.

It is this that explains the uni-polar currents, and the sparks that occur when any point on the solenoid is touched. In this case the body, constitutes an insulated surface which, at each oscillation, is charged with a very nearly constant quantity when it is at a certain distance from the solenoid.

The corresponding charge of contrary sign should be

found on the parts of the solenoid which are at that moment at a different potential. This explains why the sparks which are drawn from the solenoid are greatest at the extremities and least midway.

3d. The resonant effects, which have been so beautifully shown by the experiments of Hertz, and which are extremely interesting to the physicist, but which have not, so far, been found to have any relationship to therapeutics.

#### METHODS OF APPLICATION.

In bringing the action of these high frequency currents to bear upon the human and other animal organisms three methods of application have up to this time been employed—suggested by the properties of the current which we have enumerated.

1st. Auto-conduction. In this mode of application the capacity of the current to induce currents in objects brought within their range, is utilized. In place of the small solenoid above described a much larger one is employed, composed of well insulated cable wire, and wound about a frame work capable of admitting into its interior the man or animals to be treated. Although the person enclosed in the solenoid is not in contact with it at any point, nevertheless, while it is in action, induced currents of extreme energy and frequency of oscillations are induced in his body. These induced currents have their seat in the organism itself and act upon the central nervous system and deep seated organs and tissues as is shown by the effects produced and recorded in the following article on the physiological action of these currents.

2nd. The direct application. This is made by conducting the currents generated in the small solenoid, or the currents of second order, to any part of the body by

means of conducting wires and metallic electrodes and thus making the body as a whole, or any part of it, as the case may be, a part of the circuit.

3rd. Insulation. In this method the patient, person or animal, to be subjected to it is placed upon an insulated platform and connected by a wire to one extremity of the solenoid while a point, metallic point or plate, at some little distance from the insulated platform is connected with the other extremity of the solenoid. The person acted upon is thus, as it were, made to take the place of one of the armatures of a condenser and is subjected to a charge which is slowly discharged by connection across the interval between the body and the conductor leading to the other extremity of the solenoid.

PHYSIOLOGICAL ACTION OF HIGH TENSION, HIGH FRE-  
QUENCY CURRENTS.

This form of electric modality, except as it is furnished by static or influence machines has not so far been studied in its relation to physiological action by many persons. Several notable electricians as Nikola Tesla, Elihu Thomson and Hertz have done much to acquaint us with the apparent harmlessness of this form of electricity when the living animal body, or some part of it, is made the path of its transit. But to d'Arsonval and his assistants the credit is mainly due for having determined with scientific exactness and demonstrated by unquestionable proofs that this electric modality does in many ways modify physiological processes most profoundly. While we have for a number of months been using this form of electricity in this laboratory, as generated by both the Tesla and the Thomson forms of apparatus, we have, so far, done little with it other than to confirm many of the

results that d'Arsonval has reached and which he has published from time to time in the transactions of the Société de Biologie and of the Société Internationale de Physique.

What is set forth here, therefore, as the result of investigation as to the relation of this form of electricity to physiological action in the animal body, and which may be regarded as fully established by abundant experiment, is given mainly on the authority of d'Arsonval, and to the detailed reports of his researches we would refer any who may wish to examine into the data upon which the following conclusions are based:

1st. The most singular and striking effect of high-tension, high-frequency currents is their entire absence of action on sensation. This is daily demonstrated in this laboratory. When the Tesla apparatus is excited by an alternating dynamo current and is pouring forth a torrent of sparks between the terminals, across an air gap of eight or ten inches, one can grasp these terminals, one in each hand, and take the entire current through the body without experiencing the slightest sensation except, perhaps, one of gentle warmth at the wrists when the current reaches, or exceeds three amperes. To demonstrate the actual energy that is being expended during this procedure it needs only to have two persons grasp these terminals each with one hand and then complete the circuit by taking several incandescent lamps in series between them, when the lamps, requiring each an ampere of current and 100 or more volts to light them, will glow brilliantly while the current is passing.

When the current is caused to impinge upon a limited surface of the skin or mucous membrane in the manner which in treatments by the static machine is termed "the breeze" the part is soon benumbed and for a few moments

experiences the loss of sensibility which may go on to complete anaesthesia. This insensibility does not penetrate deeply and lasts only a few moments, but that it may be made to serve important therapeutic needs is at once evident to a physician.

2d. These currents do not excite muscular contractions. Just as the passage of these currents through the organism fails to arouse sensation so likewise motor nerve and muscle are irresponsive to them. While the same quantity of electric energy transmitted under the form of alternating currents of long periods (100—10,000) and much less voltage, would have caused violent muscular contractions, which of themselves would suffice to kill the recipient, here no contraction whatever occurs.

But just as a sensory nerve when subjected to the direct action of these vibrations for a time is rendered anaesthetic, so a motor nerve may be influenced in such manner by these currents as to be for a brief period (10 to 15 minutes) incapable of responding to any form of excitement.

3d. The high-tension, high-frequency currents impart an extraordinary activity to nutritive changes and to cellular life.

This has been demonstrated.

(a) By examining and estimating in man and animals the products of respiratory combustion before and after the action of the current. The oxygen absorbed is seen to be increased considerably and carbon dioxide is eliminated in greater quantity.

(b) By the amount of urea being greatly increased in quantity, as has been determined by hundreds of urinary analyses.

(c) By an increased heat production, which has

been carefully determined by an ingenious anemo-calorimeter devised by d'Arsonval. By this instrument it has been established that by comparing the heat put forth by the human body before and after this method of electrization, it is found to raise it from 79.6 cal. to 127.4 cal. per hour at an average temperature of  $17^{\circ}$  C.

(d) By a loss of weight in the men and animals experimented on during the period of application. This would of necessity be the primary result of the increased combustion. But it was found that in the intervals between the applications of the current there was a rapid gain in weight.

4th. While there is no perceptible action of these currents on the nerves of general sensibility and of voluntary muscle, the vaso-motor nervous system which controls the vascular system is influenced by these currents to a marked degree. The blood vessels in the ear of the rabbit are seen to dilate rapidly under its action and this is followed a little later by energetic contraction. The same results take place in man as determined by the sphygmograph and sphygmomanometer. The blood pressure is at first lowered and after a little time rises and remains elevated.

5th. Action on unicellular organisms. In order to determine the direct action of these high-frequency, high-tension currents on cellular physiology many forms of bacilli were subjected to their influence. The cultures of the pyocyanic bacillus were very much attenuated at the end of some minutes. The chromogenous function is first suppressed and if the experiment is continued for half an hour the bacilli are killed.

The action of these currents is found to modify also the products of the secretion of bacteria. The microbic

toxines are found to readily lose their virulence when subjected to this electric modality for a short time.

D'Arsonval and Charrin have carried on a series of experiments for some months to determine the modifying action of various forms of electricity on the growth and behavior of bacteria the results of which were reported to the French Academy of Sciences, February 10th, 1896. Their experiments have shown that cultures of bacteria are affected more or less by the action of the constant or galvanic current, the interrupted induced current of low tension and frequency, and also by the high tension, high frequency currents. The action of the latter seems to be most effective both in retarding the growth of pathogenic bacteria and in weakening the virulence of their toxine products. As has been elsewhere noted, the action of the constant current upon culture media is attended by electrolysis and is a difficult matter to determine, when this current is used, just how much of the result is to be attributed to the electric action directly and how much to the action of the liberated ions. It is fair to presume that the changes wrought by the high tension, high frequency currents are the result of the electric action solely since being alternating currents but little electrolytic decomposition attends them.

The experiments upon bacterial toxines by means of high frequency, high tension currents and the subsequent tests made with the solutions containing the toxines thus acted upon, not only seem to show that the toxic power is reduced, but also that the animal receiving such injections is rendered immune, or its resisting power to such toxines is greatly increased. From this the hope is entertained that by means of the application of such currents it may, eventually, be possible to so attenuate bacterial products

in the organism of a patient as to render him immune to the disease.

6th. The clinical results are also in evidence to prove the modifying influence which electricity in this form exerts upon physiological action, and while these are not as yet very abundant they are already sufficient in amount and importance to establish the value of this unique manner of treatment, and are deserving of separate consideration in the following article.

#### THERAPEUTICS OF HIGH POTENTIAL, HIGH FREQUENCY CURRENTS.

Those who have been long familiar with the results obtained from treatments by means of the static machine cannot but be struck with the similarity of these with what has recently been set forth by D'Arsonval, Apostoli and a few others as the results of their experience in the therapeutic use of high frequency currents obtained through the variously devised forms of apparatus that they have employed. Especially do the results on general nutrition obtained by the spark and insulation methods of treatment by the static machine closely correspond with those reported as resulting from the inductive action of the large solenoid. The assertion which is often made that "suggestion" is accountable for much that is reported as resulting from this as from other forms of electric treatment falls to the ground in the face of the exact methods of analysis that have been adopted in determining the effects of these currents on patients in the public clinic and upon the growth of infants in the Maternity hospital. But the field is open and those who doubt may readily put all assertions to the proof.

We perhaps cannot do better in our attempt to set

forth the present state of opinion as to the therapeutic range and value of this peculiar electric modality than to give as succinctly as possible the conclusions of Apostoli, whose clinical experience in this field has been up to the present time far more extensive than that of any other practitioner.

They are as follows:—

1st. The alternating currents of high tension exercise a powerful action on every living organized body which is submitted to their influence.

2nd. The best method of treatment by means of these currents is to enclose the patient, without any contact whatever, in a large solenoid traversed by the current. The patient is thus completely insulated from the electric source and the currents which circulate by “auto-conduction” in his organism have their origin, by induction, in the tissues themselves. The body here plays the part of a closed circuit.

3rd. The powerful influence on the vaso-motor system claimed for these currents by d’Arsonval has been verified, although the sensation immediately produced by their passage is nil, and there is no impression made by them on motor nerves or muscles. But an energetic action on all nutritive exchanges may be noticed. This action shows itself by an over-activity of organic combustions and of nutrition, as has been shown by the analysis of the respiratory and urinary excretions made by d’Arsonval, Berlioz and others.

4th. The general therapeutic applications which follow from this physiological action are confirmed in the clinic.

At the time of this report (made at the London congress in '95) Apostoli had in this manner treated more than

one hundred patients, covering a period of a year and a half, some in his office and some in his public clinic. The greater number of them were much benefitted by this method, which was used to the exclusion of all other treatment or medication.

5th. These currents exercise, in the majority of cases, a powerful and generally reparative action on diseases caused by or attended with feeble nutrition, by accelerating the organic changes and by increasing the activity of enfeebled or perverted combustion and elimination. Diuresis becomes generally more satisfactory and excretion is hastened.

6th. Generally in patients submitted to this influence daily for about 12 minutes the following effects are noticed about in the order named:—

Return of sleep.

Increase in force and vital energy.

Return of good feeling, capacity to work, ease in walking, increase of appetite.

Progressive and complete restoration of the general health.

Often from the first sittings and even before the special and local effects noticed as changes in the excretions, etc., an amelioration of the general ill-state can be plainly noted.

7th. The local troubles, pains or trophic disturbances, subside generally much more slowly under the modifying influence of these currents than general nutritive disorders. In many cases such local disorders require the addition of local treatment.

8th. Of all the diseases, which up to the present seem to yield to this treatment, rheumatism is most energetically and effectively influenced.

9th. In some cases of diabetes the sugar has rapidly disappeared from the urine, while in others it has not been perceptibly diminished in spite of the manifest improvement in the general state. This difference in result may be due to a lack of uniformity in technique or to different pathological conditions.

To sum up in the words of d'Arsonval, electricity in the form of high tension, high frequency currents is the most powerful modifier of the intimate nutrition of the tissues that we know.

It is a modifier which attacks life in its most intimate manifestations and which touches the working of the living cell itself. Its action extends even to the products of the cell. As these currents can with impunity traverse the organism of living man there is no temerity in saying that by means of them an entirely new road for therapeutics is opened up.

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## THE STATIC MACHINE.

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We have in the beginning of the preceding article discussed the static machine as a source of high potential high frequency currents. While, as there stated, it cannot be depended upon to furnish currents oscillating in character or of a uniform rate of oscillations, yet the electric modalities derived from the static machine have for many years proved of valuable service in therapeutics.

Static, or frictional electricity is the form in which this agent was first brought to the intelligent attention of mankind and by which, therefore, it has been longest known. The physiological effects of the static spark derived from the crude apparatus of Von Guericke of Magdenburg, as early as the middle of the seventeenth century,

was the means of directing the thought of physicians to electricity as a therapeutic resource. But the machinery for generating static or frictional electricity had to go through many successive stages of experiment before it furnished an instrument that could be relied on for therapeutic work.

The invention of influence machines by Holtz and by Töpler in 1865 met this want, and these with the later invention of the Wimshurst machine now amply supply us with instruments for dealing with such abnormal conditions as can be successfully combated by means of static electricity.

In the Holtz machine the original or primary charge must be supplied to the machine, and this under suitable conditions is multiplied by induction as the movable plates are rotated. When at rest, however, and when the atmosphere is warm and humid, this machine readily loses its charge and is at times recharged with much difficulty. The Töpler and Wimshurst machines are self exciting. This feature in their action is obtained through augmenting the slight difference of potential that usually exists by means of metal buttons, more or less in number, attached at regular intervals to the surface of the revolving plates and projecting so as to come in contact with metallic brushes of tinsel or fine wire fixed on the ends of metal rods. The friction caused by some of these brushes augments the initial charge while others of them serve the purpose of discharging, by contact, the electricity accumulated on that part of the plate which passes them. The presence of these brushes, buttons and metal inductors on the Töpler and Wimshurst machines are somewhat of a detriment to their insulation, and in this respect render them inferior to the Holtz, of the same size, in the amount

of electric energy produced. But the conditions which furnish the initial charge by friction in the former machines are constant while they are in motion, each revolution adding its increment of difference of potential from this source, which renews the supply of electricity and

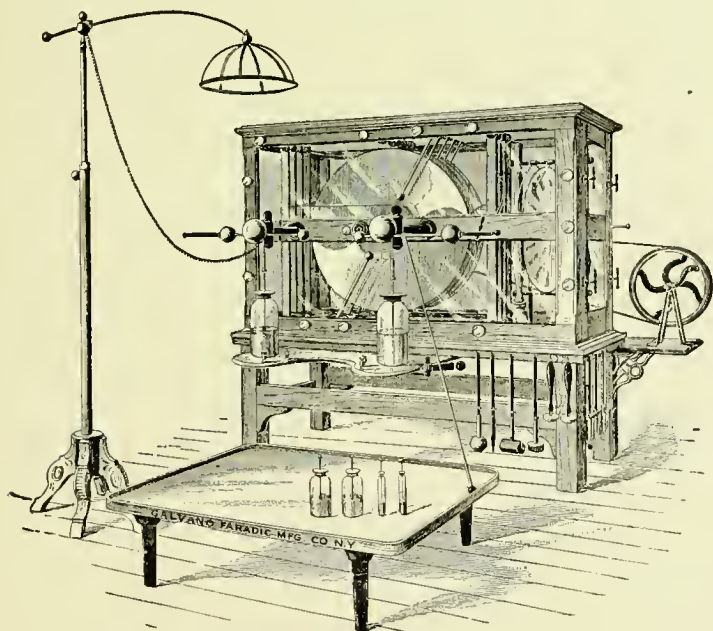


FIG. 46. HOLTZ MACHINE.

makes the generating capacity of these machines more constant and reliable.

The manufacturers of the Holtz machine for medical use have of late years furnished it with a small Wimshurst for the purpose of exciting action in the Holtz when it loses its charge, and the latest improved static machine of the Holtz variety has a small Wimshurst included in the case with it, so arranged that a charge from the small ma-

chine can be readily transferred to the plates of the larger one.

The Wimshurst machine is especially reliable in creating a difference of potential and getting into action because its construction is such as to give a large amount of friction between the metallic brushes on the stationary plates and the carriers on the revolving plates. These metal carriers or sectors are greater in number than on the Töpler machine and the arrangement which causes the revolving plates to move in opposite directions favors a rapid development of the charge. The mechanism of the Wimshurst is not, however, well adapted to secure durability in a machine of large size, so that they are not so well suited for developing quantity of electricity as either the Holtz or Töpler form.

All static machines for therapeutic work are now provided with Leyden jars as condensers, so as to increase the quantity of electricity in the resulting spark. When the machine is in action the interior of one Leyden jar becomes charged positively, the other negatively, and the outer coating of each jar by induction becomes charged with an equal but opposite potential from that within. By leading off conductors from the outer coatings of the Leyden jars, an induced current can be obtained and utilized for therapeutic purposes. This current has been named by its discoverer the "static induced current" and resembles somewhat in nature the current derived from the fine wire coil of a medical induction coil, as it is an alternating, and interrupted current, but its potential is very high, the E. M. F. being far in excess of that which any medical induction coil can furnish. The frequency of interruptions of this current depends upon the frequency with which discharges take place between the interior ar-

matures of the Leyden jars at the spark gap which separates the prime conductors, and as the width of this spark gap is under the control of the operator the number of interruptions and the strength of the "static induced" current can be varied at will.

The resistance which the static machine is able to overcome at the instant a spark crosses the air gap between the prime conductors shows us that we are here dealing with electricity in a state of very high potential. The E. M. F. of the direct currents which we have heretofore considered as adequate for electro-therapeutic work is entirely inadequate to carry a current across the resistance of the minutest air gap. And the most powerful medical induction coil now in use gives an E. M. F. capable of forcing a passage through but an infinitesimal film of air resistance. But well constructed static machines of fair size will readily develop an E. M. F. that will cause the current to leap an air gap between the prime conductors of eight or ten inches (20 to 25 cm). The E. M. F. required to overcome the resistance offered by such a large interval of dry air is enormous. Although no careful measurements of the E. M. F. of the static machine are yet recorded, a rough estimate can be made from the size of the air gap traversed by the current as shown by the spark.

A spark 1 mm. in length would indicate an E. M. F. of

at least.....	2,000 volts;
One of 1 cm.....	10,000 volts;
One of 10 cm .....	100,000 volts;
One of 25 cm .....	1,000,000 volts

approximately.

But while the voltage is extremely high the current actually passing is exceedingly small, seldom more than the fraction of a milliampere.

The spark is the result of a sudden breaking down of the dielectric; that is, the air stratum between the prime conductors. "The difference of potential has so far increased by the working of the machine that the air stratum no longer offers sufficient resistance; it is in a state of gradually increasing strain and finally gives way and a discharge of electricity takes place equalizing the potential. The spark is not itself electricity, but it is due to the heat and light generated in the intervening particles of matter as a consequence of the mechanical violence of the disruption. The discharge which causes the spark is apparently unidirectional but in reality it is oscillatory in character, the rapidity of the oscillations occurring with marvelous frequency and gradually decreasing amplitude." The vibrations of one discharge may reach as high as a hundred million or more per second.

The difference of potential which is created by the action of the static machine seeks relief from the strain produced on the surrounding insulators or dielectrics in other ways than through the sudden disruption which causes the spark discharge. Foreign substances suspended in the atmosphere as dust, or water vapor, become charged with electricity of different potentials and are repelled from the attracted to different parts of the apparatus, according to the polarity. A stream of such particles may produce an actual current in the air if escaping from some point or edge where high degree of difference of potential is maintained. This is what constitutes the so-called "electric breeze" and if it is accompanied by noise and light it is termed a "brush discharge."

It is sometimes desirable to know, when using a static machine in therapeutic work, which prime conductor has positive and which negative potential. The position of

the prime conductor or Leyden jar will not serve to designate the potential since in the action of the machine the potential may become reversed. The most satisfactory method for determining which conductor is positive and which is negative is to observe the machine while in action in the dark, when the positive side can be recognized by the tips of the collecting comb showing points of light while upon the opposite or negative side the light appears in brush-like form.

In order that a static machine may be kept up to its highest efficiency care must be taken to preserve intact the conditions essential to its action. Dust or moisture upon the plates rapidly equalizes the difference in potential created. Variations in the amount of moisture in the atmosphere affect the working of the machine. It is best, therefore, to have the plates of the machine enclosed in a case where they can be kept free from dust and where if necessary the air can be subjected to artificial methods of drying, either by means of a dish containing petroleum or anhydrous calcium chloride placed within the case. All unnecessary points and projections should be avoided in the construction of the machine since they serve to dissipate the electric energy produced.

The increase in the size and number of the plates increases the quantity of electricity, but there is a point beyond which such increase possesses no additional therapeutic advantages. The prevalent opinion at present among those experienced in the use of static electricity in therapeutics is that a machine having eight plates, four revolving and four stationary, the revolving plates being from 28 to 36 inches diameter, is capable of doing all that is at present sought for from a machine of this kind.

## PHYSIOLOGICAL AND THERAPEUTIC ACTION OF STATIC ELECTRICITY.

We have considered the structure and action of static machines for therapeutic work and the physical properties of the electric energy which they produce. It remains for us to study the behavior of the human organism in health and disease when subjected to electric conditions such as the static machine and its accessories can furnish.

The extremely high electro-motive force of electricity when generated by the static machine renders it prone to break down the dielectric which surrounds all conductors and other bodies charged with it and so escape. The dielectrics or insulators that are employed in the operation of the static electric machines which physicians use are the glass plates of the machine itself, the glass of the Leyden jars or condensers, the glass or hard rubber used for the various supports of the conducting parts of the machine as well as for the feet of the insulating stool, and lastly, the air which surrounds all parts of the machine and the objects in continuity with its conductors. In order that a body may be subjected to a high degree of static charge these various dielectrics must be capable of sustaining considerable strain without giving out, that is, there must be a sufficiently thick layer of air or glass or hard rubber separating from surrounding objects the bodies and conductors which the machine has brought to a positive potential so as to prevent the charge from escaping to the earth through some object which is in connection with it, and may serve as a conductor. Particles of moisture or dust in the atmosphere which surrounds the machine aid in dissipating the charge which the machine creates, and for this reason a dry atmosphere and one free from dust

is an essential if a static machine is to do its most successful work.

The physical conditions created by means of static machines that are employed in therapeutics may be enumerated as follows:

- Static insulation,
- The direct spark,
- The indirect spark,
- The friction spark,
- The spray or breeze,
- The needle spray,
- The static induced current.

**Static Insulation or Charge.**—A patient to be subjected to this condition sits upon the insulated stool or platform, which is attached to one or other, usually the positive, pole of the machine by means of a conducting chain or rod. When the machine is put in motion the body of the patient, thus forming the terminal of the conductor, is raised to such a potential as the machine is capable of producing, and the patient becomes the storehouse of a positive or negative charge, depending in amount upon his or her electrical capacity. Just here there is need of some careful study in the comparative effects of positive and negative insulation. It is very generally agreed among those who have employed this form of treatment that it is followed by marked nutritional effects, yet some claim that positive insulation is stimulating and beneficial, and negative insulation is depressing and hurtful, while others assert that there is no such noticeable difference in effects between them, but that either form of insulation will prove tonic and invigorating. Only a carefully arranged series of tests faithfully carried out in both the domain of physiology and therapeutics can satisfac-

torily settle this mooted question. It is claimed for static insulation, and as commonly employed this means positive insulation, that it will elevate a subnormal temperature, or lower a temperature abnormally high; that it will regulate and increase the volume of the pulse; that it will decrease the number but increase the depth of respirations; that to a person nervously excited and sensitive, it imparts a sedative effect and a sense of well being. The action appears

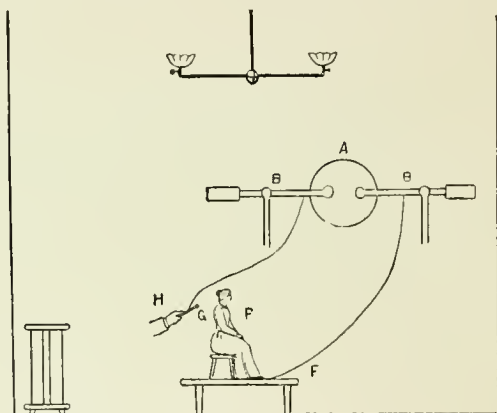


Fig. 47.

to be to improve nutrition and regulate disordered function, although the manner in which a static insulation or bath operates to produce this effect has not yet been explained.

**The Direct Spark** (Fig. 47).—In giving the direct spark, the patient is placed upon the insulating platform (F), which is connected by the chain or rod to either the positive (B) or negative pole of the machine, and the first effect upon the patient (P) is to produce a static charge of either positive or negative potential, as the case may be. Here again the positive charge for the patient is ordin-

arily used and preferred. An electrode (H) terminating in a metal or gilded ball about two inches in diameter is attached to the other pole of the machine (B<sup>1</sup>). When this electrode is made to approach the body of the patient at any point, the layer of air which surrounds the patient and acts as a dielectric is thereby rendered thinner (G), and less capable of sustaining the strain to which it is subjected, and finally it is so thinned by the nearer approach of the ball electrode that it gives way and the static charge in the patient's body suddenly becomes transformed to current electricity and escapes, leaping the air space in its transit and causing a spark.

The physical phenomena here are the sudden dissipation of a static charge which had been maintained in the charged body at a very high potential. The discharge is often if not always oscillatory in character, the oscillations numbering many thousands per second. The current by reason of the extremely high resistance to be overcome at several points in the circuit, is very small, usually but a fraction of a milliampere. The human organism, which is for us the point in the circuit of greatest interest, is suddenly subjected during a treatment of this nature to a high electric potential, which it as suddenly loses as often as the ball electrode is brought sufficiently near to some part of the body to cause sparking. As all parts of a charged body are at a uniform potential a change must take place throughout the entire organism when the potential is reduced to zero, as is the case when a spark crosses the air gap, and if this discharge is not instantaneous in its decline of potential but oscillatory, with gradually decreasing amplitude of oscillations, the organism must be subjected to corresponding disturbances in its molecular arrangement throughout. The tissues of the human body are not uni-

form in conductive capacity, consequently the density of the charge is not uniform throughout the entire organism. Both during charge and discharge therefore, the human body must be supposed to act quite differently from a mass of metal of equal size and form under similar electric conditions. Certain of the tissues conduct readily while others possess the characters of dielectrics. There would, therefore, be innumerable spots of strain and slip in close relation which must be taken into account when we attempt to analyze the effects produced during a static treatment. But whatever may be the fact as to the spark discharge causing molecular excitation of the entire organism, a series of phenomena capable of ocular demonstration always occurs at that part of the body where the discharge takes place. There is a sudden blanching of the skin, due to vaso-motor constriction over a circular spot greater or less in diameter, according to the strength of the discharge; this is soon followed by a vaso-motor dilatation and the spot is correspondingly reddened, a condition which remains for a considerable length of time after the treatment. The muscles underlying the point from which the discharge takes place are caused to contract and sensations of a variable nature, referred to the same spot, are prominent accompaniments. These sensations are an important element in the treatments for upon their nature often depends the good or bad effect which the patient experiences. The direct spark from small machines is much more likely to be stinging, pricking and irritating than from large machines, and it is claimed that grounding the machine has the effect to render the spark much less disagreeable than when the circuit is confined to the machine, the conductors and the patient, as is the case when using the direct spark. The static spark is of great value in

arousing to more active nutrition any organ of the body that is subjected to this treatment. The skin, the vascular tissues, muscles and nerves are stimulated by it. Its effects are more generally distributed throughout the body than is the case with the direct or induced current applications, so that it is well suited for correction of systemic disorders, such as rheumatism, gout, neurasthenia, spinal irritation and general sluggishness in nutrition from whatever cause. Unmistakable evidence is given of its power to quicken nutritive processes by the way in which the sweat and sebaceous glands are set to work by it, and the improved bodily comfort that follows such applications, is due in a great measure, no doubt, to the more perfect elimination of effete matters from the body.

It is sometimes difficult to give the spark treatment to special localities of the body by means of the ordinary ball electrode for the reason that the current which causes the spark invariably seeks the line of least resistance. A directive electrode, such as the Morton electrode is of much service in getting exact local effects, and by means of it the spark can be drawn from accessible surfaces within the cavities of the body when this is thought desirable.

**The Indirect Spark** (Fig. 48.)—In order to get the indirect spark the machine must be “grounded.” This is done by putting the negative prime conductor or pole of the machine in communication with the earth by means of a conductor running from it to a convenient gas pipe or water-pipe. The electrode used for the purpose of drawing sparks should also be grounded. This has the effect of increasing the quantity of electricity which the machine generates and improving the constancy of its action. The spark is likely to have more volume and is cleaner, with less irritating properties. It is more satisfactory, there-

fore, when using the spark treatment to have the machine grounded. A sputtering series of sparks is very disagreeable to most patients and irritates the sensory nerves and should always be avoided except when this effect is sought for, as in the case when counter-irritation or skin excitation is desired. It insures a clean, full, individual spark

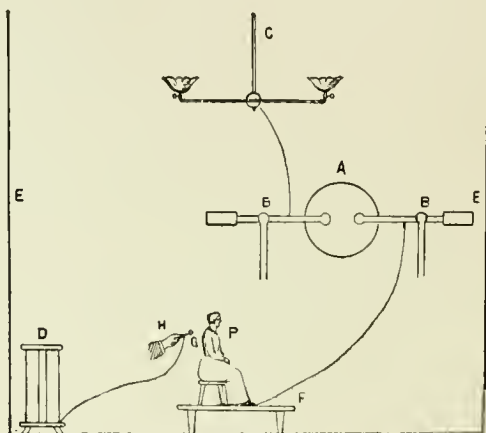


Fig. 40.

to have the machine well grounded and then make the ball electrode approach the part of the charged body suddenly to within the proper distance and as suddenly withdraw it.

The purpose and manner of the treatment with the indirect spark is the same as that with the direct spark, but the effect differs because of the physical and physiological differences which they possess.

**The Friction Spark.**—This is used mainly for excitation of the skin or the superficial blood vessels and is a convenient method for applying mild counter-irritation. The patient is insulated as with the spark treatment. A roller electrode is provided for this application but is not necessary since the large ball electrode will serve the same

purpose. The only physical difference between this and the direct or indirect spark is that the dielectric is thinned down to a layer which is represented by the thickness of the patient's clothing. The roller or ball is passed over the spot treated directly in contact with the clothing, consequently the charge escapes at more frequent intervals and with smaller sparks but with a prickling, biting or stinging effect upon the sensory nerves of the skin which is decidedly exciting to their function and the reflex effect upon the nutrition of the skin is marked.

This form of treatment is of special service in correcting chronic malnutrition of the skin as in eczema and sensory paresis.

**The Spray or Breeze.**—Again the patient is insulated as before but the charge is withdrawn, not suddenly, as in the forms of treatment thus far mentioned; but slowly and in infinitesimal quantity by holding a pointed electrode at such distance from the part of the body to be treated that the discharge is not disruptive but is conveyed away by the particles of air forming the dielectric layer, each becoming charged with its load and seeking the opposite potential. This creates a current in the atmosphere surrounding the part of the patient's body under treatment. This motion together with the gentle stimulating effect caused by the slight loss of potential in the surface which each instant takes place by the process of convection that is going on, constitutes the treatment.

The pointed electrode may be moved about over the patient's body. Or, by fixing it upon a stand, it can be so placed that the effect may be maintained for any desired length of time upon a particular part. A circle of points fixed at a suitable distance above the patient serves to distribute the "spray" or "breeze" uniformly over the head,

The static spray or breeze is peculiarly soothing and resting in its effects. By means of it a condition of nervous excitement and restlessness can be almost immediately allayed. Severe headaches of a nervous type are often quickly relieved and insomnia is frequently overcome.

**The Needle Spray.**—When only a part of the patient's body is brought in the direct line of charge, and so is raised to a higher potential, as would be the case if the conducting chain is held in the patient's hand instead of being placed on the insulating stool, and the pointed electrode is then brought near enough to the part to be treated to allow of minute disruptive drops of potential instead of the discharge by convection, the effect upon the part under treatment is much as if it was being pricked by innumerable fine needles. This is decidedly stimulating, though at the same time irritating, and is in all respects of the same nature and used for the same purpose as the friction spark above described.

**The Static Induced Current.**—The static induced current is that current which results from a return to zero of the difference of potential that is created between the outer coatings of the Leyden jars or condensers attached to the prime conductors of the machine (Fig. 49). At each instant that a discharge takes place between the prime conductors, the potential difference which existed in the interior of the Leyden jars is equalized and a corresponding discharge takes place between the exterior surface of these jars and this latter current can be utilized for therapeutic applications without the disagreeable accompaniment of sparks. The electrode for applying this current can also be placed in contact with the body and the various tissues and organs be brought under its influence with more precision than is possible in the use of the spark or

spray. All modern static machines designed for therapeutic work are furnished with connections that permit the use of the static induced current. For the regulation of this current it is only necessary to regulate the discharge between the prime conductors of the machine. A small spark gap permitting frequent minute discharges will be attended by a similar frequency and feebleness in the static induced impulses. A wider separation of the prime conductors will result in heavier discharges at longer intervals. The strength and frequency of the impulses of the static induced current is thus readily controlled. The nature of

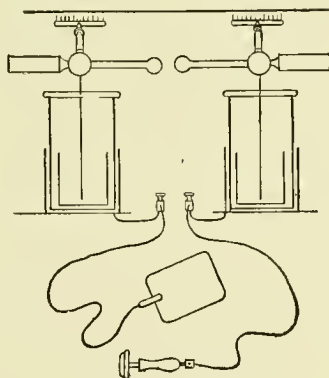


Fig. 49.

this induced current is similar in potential to that of the inducing current. The milliamperage depends upon the resistance offered in the circuit. It is in all probability, at times at least, oscillatory in character, although this remains to be determined with certainty. As to the physiological effects and the therapeutic applications of the static induced current we quote the words of Dr. Morton, whose rich experience in the use of this current gives to his conclusions the weight of authority.

“Applied to a motor point, the static induced current produces most vivid and persistent muscular contraction with a minimum of pain; applied farther back on the trunk of a motor nerve it throws large groups of muscles into contraction. The contraction is peculiarly painless as compared with that of faradic coils, and the influence is remarkably effusive. Accompanying a contraction of a large group of muscles is a peculiar sensation of lightness and buoyancy of the member. The painlessness, diffusiveness, and buoyancy may all be experienced by holding the two electrodes in the hands, and taking a current as strong as possible. Most people will readily submit to flexions successively at the wrists, elbows, and even to the shoulders before insisting upon taking no more. The arms during the passage of the current feel as if made of cork, and this feeling of lightness persists for some time. It is the same feeling, doubtless, though here exaggerated, as is commonly referred to as the refreshing effect of general electrization. The quality of the current is such, that while energetically exciting the motor function of the nerve filaments, it fails to excite or may even annul, to an extent, the sensation of muscular pain. Its penetrating, diffusive, painless effect, with strong muscular contractions, adapt it admirably to general application over the entire body as an electric in place of an ordinary massage.

“It is, of course, applicable to every form of muscular paralysis, for there is no practical stimulus to nerve and muscle except the electric, and none more energetic than this form of it

“Its effects upon the Hallerian irritability of the muscular tissue necessarily includes an effect upon the local circulation of a part and upon the lymphatics, and to this may doubtless be referred many clinical results of relief,

as in lumbago and all forms of muscular rheumatism, sub-acute and chronic rheumatic affections of the joints, ovarian or pelvic pain, sciatica or other neuralgias.

“The second prominent characteristic of this current is its power of relieving pain. Leaving out of sight the part, be it more or less, played by circulatory changes referred to, in this respect there seems to exist a specific analgesic quality in the current. The cotton feeling in the hands and subjective sense of buoyancy in the arms is in itself an evidence of this. But the effect upon pelvic pain, upon ovaritis, upon neuralgias, pleuritic ‘stitches,’ tonsillitis, and many other pain affections is still better evidence. In sciatica, for instance, the sensation of pain is frequently quickly relieved and a cure obtained, though I think in this case the cause is two-fold—that is to say, due to both the circulatory and the analgesic effect. The same I believe to be true in the pelvic and ovarian pains.

“The results in such cases, in my opinion, are far superior to anything obtainable by a faradic or a galvanic application. An ordinary faradic current will increase the pain; the galvanic will very often relieve it. But we have in the static induced current no comparison to the electrotonic and polar effects, or in general the electrolytic effects of the direct or galvanic current. Therefore, when the static induced current has failed to act favorably, we should try the galvanic, and *vice versa*. As no observations on the purely analgesic effects of this current have hitherto been made, I must leave others to test the question for themselves.”

It will be seen from this brief review of the methods of practical application of the effects obtained by means of the static machine that it is capable of doing a variety of work in therapeutics which no other form of electrical

apparatus can accomplish; but the good results obtainable can only follow when the action of the machine is fully understood by the operator and the case to be treated is one adapted to the form of treatment employed.

EXPERIMENT 96.—Turn the crank of the static machine until the sparks are passing between the prime conductors. Notice the difference in this discharge when the Leyden jars are attached and when they are not. Also notice the effect of connecting and disconnecting the metal coatings on the outer surface of the Leyden jars. What is the explanation of these differences?

EXPERIMENT 97.—Determine which prime conductor is charged positively and which negatively. Observe what effect, if any, the discharge has upon litmus paper. Does it electrolyze? Does it move the needle of the galvanometer?

EXPERIMENT 98.—**Positive Insulation.**—Let some member of the class take the place of a patient and sit upon a stool placed upon the insulated platform. Connect the subject, by means of a well-insulated conducting cord, with that prime conductor of the static machine which is charged positively when the machine is in action.

Separate the prime conductors of the machine so that no discharge takes place across the space between them. After the machine has been in action for a few moments notice that an electric discharge will readily take place at any point on the subject's body which is approached by a conductor, as, for instance, the finger of the operator. This shows that the subject's body has received a static charge of positive potential.

EXPERIMENT 99.—**Direct Spark.**—Separate the prime conductors and unite by a conducting cord the outer surfaces of the Leyden jars. Connect the subject on the

the insulated platform with the prime conductor charged positively.

Let someone take the place of operator and connect a large ball electrode to the negatively charged prime conductor by means of a suitable cord. Then holding the ball electrode by the insulating handle and putting the machine in action let him bring the ball electrode near to some part of the subject's body, such as the shoulder or back, until a spark discharge takes place.

EXPERIMENT 100. — **Indirect Spark.** — With the prime conductors separated and the outer surfaces of the Leyden jars connected have the subject connected with the positively charged prime conductor, as in the preceding experiment. Join the negatively charged prime conductor with some near at hand gas-pipe or water-pipe which has a ground connection. This "grounds" the machine. To the same or another water or gas-pipe the ball electrode is then connected and brought near to some part of the subject's body as before until a spark discharge takes place.

EXPERIMENT 101. — **Friction Spark.** — Let the arrangement for the subject and the connections be the same as in giving the direct or indirect spark. The operator should then place the ball electrode upon some not very sensitive part of the subject's body, such as the back or limbs, and as closely in contact with the skin as the clothing will permit. Then with the machine in action the ball electrode should be moved about over the parts of the body to be treated and kept in contact with the clothing. The charge is discharged by means of fine and frequent sparks giving a decidedly counter irritant effect.

EXPERIMENT 102. — **The Static Breeze.** — With subject and connections, as in the preceding experiment, sub-

stitute for the ball electrode a metal circlet with points and suspend it a few inches above the subject's head.

Or, instead of a ball electrode, let the operator use one terminating in a sharp point and move it about near the part of the body of the subject that is to be treated. How does this method of discharge differ physically from that which causes a spark?

EXPERIMENT 103.—**Static Induced Current.**—To the outer metal coatings of the Leyden jars connect electrodes such as are used to give a treatment with the induction coil current. Separate the prime conductors so as to leave, at first, not more than a quarter inch gap between them. With the subject on the insulated stool place the electrodes on the part of the body that you wish to treat and set the machine in motion. Observe that the strength of this current is determined by the length of the spark gap which you maintain between the prime conductors, which can be varied at will.

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## DIAGNOSIS BY RÖNTGEN, OR X-RAYS.

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Any advance or improvements in methods of diagnosis is a substantial gain. Electricity had already done much to render the diagnosis of disorders of the muscular and nervous system and pelvic organs more exact, but recent discoveries of the effect of the action of high tension currents of electricity in vacuum tubes have greatly enlarged its field of usefulness in diagnosis and both surgeon and physician are now able to add the sense of sight to that of touch and hearing, in determining the state and condition of the deep seated tissues of the body.

No one can as yet set any limit to the practical appli-

cations that will be made of Röntgen rays in revealing what to human vision is otherwise unseen. Already the members of the medical profession have found from them such help as to give promise that the date of Röntgen's discovery will mark a period of advance in medical science as important as the discoveries of Jenner or of Lister. Already enough has been done to show that not only all parts of the bony skeleton, with its defects can be portrayed in minute and exact detail, but the structure of the softer tissues and organs, also, their normal outlines and density, together with their departure from the normal have to some extent been revealed to sight.

So far as is at present known the creation of these peculiar rays by means of which the human eye is enabled to see, pictured upon fluorescent screen or photographic plate, the things of the body hidden beneath the surface, is dependent upon the action of the electric current. This gives rise to another demand upon the medical profession to become practically familiar with the phenomena of electric physics. The essentials for skiagraphic diagnosis are:—

Some kind of apparatus for generating a suitable electric current.

A Crookes tube.

A fluorescent screen or photographic plate.

#### CURRENT GENERATORS FOR RÖNTGEN RAYS.

There are three forms of electric apparatus which have so far been used to generate currents suitable for producing X-rays;

The ordinary induction coil;

The static or influence machine, and

The disruptive discharge coil.

By the ordinary **induction coil** we mean one of the ordinary form of construction, such as the Ruhmkorff coil pattern, with a vibrating, or what is better, a rotating commutator break. This form of electric generator has been used more than any other by those who have experimented with X-rays. The interest in this subject has stimulated manufacturers to produce excellent instruments of this kind until now very reliable Ruhmkorff coils, capable of giving a six, eight or ten-inch spark between the secondary terminals can be obtained.

It may be safely said that a high potential capacity in the electric generator is the first essential to successful X-ray work. So that if a Ruhmkorff coil is used its capacity should be considerable. One giving a three or four-inch spark will serve for generating rays capable of making shadow pictures of the extremity of the body, but stronger action is required if the thorax, abdomen or pelvis needs to be traversed by the rays. It is best to take the initial current used to excite the coil from some constant and uniform source of supply as storage batteries or a direct current dynamo circuit such as is used in some places for producing incandescent light. The intensity of current needed depends very much upon the condition of the tube that is used, but with a coil of large capacity the action of the coil can be varied to suit the requirement of the tube.

**A Static Machine**, when run by a motor, and constant in action is a good Röntgen ray exciter because of the high potential it creates. It is the current resulting from induction in the outer coating of the Leyden jars attached to the prime conductors of the static machine that is used—the so-called “static induced” current. Rather more care is needed to preserve the tubes from

perforation when using the static machine as a generator than when using the coil since there is liable to be considerable variation in the strength and volume of the sparks between the prime conductors even with the same spark-gap interval. A four or six plate machine with plates of from twenty-four to thirty-six inches in diameter, if its action is good, will serve very well as an X-ray producer.

But if we are to depend upon Röntgen rays and skiagraphs or flourosopes to aid us in diagnosis there must be no limit to the quantity or penetrating power of the needed rays. Both the Ruhmkorff coil and the static machine have their limitations. In the former they are due to its mechanical construction and in the latter the expense and lack of constancy in action. Some form of cheaply constructed **disruptive discharge coil** of the Tesla or Thomson type producing high-tension, high-frequency currents, and which could be attached to a dynamo circuit, such as is now so universally employed for illuminating purposes, gives promise of meeting the requirements in furnishing a convenient and reliable source of electric energy of any potential desired for exciting vacuum tubes.

Under these conditions torrents of high frequency discharges pass between the discharging knobs of the induction coil which are separated to the distance of, perhaps, 5 millimeters, the frequency being determined by the capacity and inductance of the Leyden jar circuit including the Tesla primary. These high-frequency discharges induce in their turn high-frequency and high-potential discharges in the tube. In such cases both electrodes of the tube are alternately cathodes, and the glass wall opposite to each electrode becomes fluorescent and therefore the source of Röntgen rays.

## VACUUM TUBES.

Perhaps no part of the apparatus required, in the present stage of our knowledge, for the production of Röntgen rays has received so much attention as the vacuum tubes in which the antecedent cathode rays are generated. A volume could be written upon this subject and what can be said in a few paragraphs will perhaps to some appear very meagre. We must refer those who wish to investigate the subject more deeply to the pages of the electrical and scientific journals or to some special work on the subject.

Success in making skiagraphs depends very largely on a familiarity on the part of the operator with the action of the tube and the changes that may take place in it while undergoing bombardment.

*Shape of the Tube.*—It is now well known that the best tubes for producing efficient X-rays are those so constructed as to concentrate or focus the cathode rays either on a reflecting surface within the tube or a convenient spot on the wall of the tube itself.

The source of the X-rays is the point against which the cathode rays are first projected. Whether this be the wall of the tube or some other surface within the tube. The cathode rays can be concentrated upon this point both by the shape of the cathode electrode and the shape of the vacuum. It is well, therefore, to give such convexity to the shape of the cathode as will focus the cathode rays at a desired point. Cathode terminals made of aluminum seem to work best, and since the material of the cathode is gradually worn away by the action, the size and thickness should be considerable. If it is designed to have the cathode rays first strike the wall of the tube and there create X-rays, the anode terminal may be of

aluminum also and terminate in a point or in a ring; the latter is better since it does not heat so quickly. But if the anode terminal is to be used as the point of contact or impingement of the cathode rays and so generate the X-rays, then it is best to have it made of a sheet of platinum and set at such angle as will direct the X-rays to emerge at the spot on the tube where the glass has been purposely blown thin. When the X-rays are once created their escape from the tube should be facilitated as much as possible, and this is best done by having the glass at the point of their exit blown as thin as is consistent with the safety of the tube.

A long narrow tube, therefore, with comparatively thick walls, but thinned opposite the point of impact or emergence of the X-rays appears to be the most efficient shape. The best work has been obtained from this, or from some form of "focus" tube. The length of the tube should be selected to correspond with the potential used. The higher the potential the longer the tube will need to be, and if a very high potential, as from a disruptive discharge coil, is used, it may be found necessary to limit the electro-static action created about the tube by immersing it in oil.

*The Vacuum.*—More seems to depend upon the electric potential employed than the degree of rarefaction within the tube, for even with comparatively low vacua X-rays are generated with high potentials. The vacuum increases very much during the action of the tube. This is thought by some due to an actual propulsion of molecules through the walls of the tube, while others believe the walls absorb and retain the gaseous particles. When from action the vacuum grows so high as to impede the discharge through the tube, it can be readily reduced by

gently heating the tube with the flame of a spirit lamp or Bunsen burner. The heating appears to set free the gaseous particles from the walls of the tube. The degree of vacuum suitable for generating X-rays bears direct relationship to the electric excitation and the best action of any tube can only be determined by experience with it.

*Action in the Vacuum Tube.*—This has been most graphically and accurately portrayed by Tesla. “When the Crookes phenomena show themselves most prominently there is a reddish streamer issuing from the electrode, which in the beginning covers the latter almost entirely. Up to this point the bulb practically does not affect the sensitive plate although the glass is very hot at the point of impact. Gradually the reddish streamer disappears, and just before it ceases to be visible the bulb begins to show better action, but still the effect upon the plate (or screen), is very weak. Presently a white or even bluish stream is observed, and after some time the glass on the bottom of the bulb gets a glossy appearance. The heat is still more intense and the phosphorescence through the entire bulb is extremely brilliant. One should think that such a bulb must be effective, but appearances are often deceitful, and the beautiful bulb still does not work. Even when the white or bluish stream ceases and the glass on the bottom is so hot as to be nearly melting, the effect on the plate is very weak. But at this stage there appears suddenly at the bottom of the tube a star-shaped changing design, as if the electrode would throw off drops of liquid. From this moment on the power of the bulb is increased ten-fold, and at this stage it must always be kept to give the best results.”

## FLUORESCENT SCREENS AND SENSITIZED PLATES.

The quality which certain substances possess of fluorescing when exposed to these invisible rays was not only the road to their discovery, but serves as a very ready means for detecting the presence and quantity of the rays. Röntgen made use of a fluorescing screen made of platino-cyanide of barium. Salvioni had none of this material at hand when he wished to construct what he has termed his **cryptoscope**, but tried calcium sulphide, which he found worked very well. He spread it on to the card-board end of a tube by means of fish-glue, while in the end of the tube near the eye he placed a lense which made the card-board phosphorescing under the influence of the X-rays, more distinctly visible. Following in this line of experiment Edison not only discovered a long series of substances which fluoresce under the influence of X-rays, but he found among them tungstate of calcium to be by far the most efficient, and from these researches **fluoroscopes** were developed which now are indispensable to skiagraphy. A thin film of fluorescing material placed in contact with the photographic plate greatly reduces the time of exposure for making a negative.

The fluoroscope does not take the place of the sensitized plate in diagnosis, for the shadows cast upon it are not so sharp and distinct as those formed on the photographic film, and it leaves no permanent record. Yet it serves as a rough and ready means for examination and is most helpful in determining the action of the tube and fixing upon the best time for an exposure of the plate.

Serious injury to the skin and sometimes to deeper tissues is caused by too prolonged or too intense action upon them of some influence emanating from the excited Crookes tube. While it is not yet positively known what

causes this injury, it is in all probability due to a bombardment of the tissues by microscopic particles of metal or glass carried off from the metal of the electrodes or the glass of the tube and driven into the tissues by the action of the static charge which they possess. It is found that if a thin sheet of aluminum or wire gauze of the same metal is placed between the Crookes tube and the part of the body being skiagraphed, and is then grounded it will effectually prevent any injury to the tissues. As such a grounded screen would serve to draw the static charge as well as to intercept the particles, the result of its action well accords with the theory above advanced as to the cause of such injury.

EXPERIMENT 104.—Excite the Crookes tube by means of the static machine or the induction coil, and observe by means of the fluoroscope the relation between the naked-eye appearance of the tube and the illumination of the fluoroscope screen. Observe the defining power of the rays on the bones and joints of your hand and wrist, placing the hand undergoing examination directly in contact with the outer surface of the fluoroscope.

EXPERIMENT 105.—Use a six by eight sensitized plate or film enclosed in a thick layer of dark paper or in a plate-holder, and placing some part of your hand or arm in contact with it at a distance of eight or ten inches from the Crookes tube, excite the tube for four or five minutes in such manner as you have found generates X-rays most abundantly. Then carefully develop the plate or film and study the result. Be careful not to expose the sensitized plate to the action of the X-rays before you are ready to make the picture or after it is taken.

## RELATION OF MAGNETISM TO LIVING ORGANISM.

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The intimate relationship existing between electricity and magnetism, the inseparableness of their phenomena, make it more than probable that when electric energy is operating magnetic stress must be credited with a portion of the work accomplished, and *vice versa*. Whenever a current of electricity traverses an animal body in any direction the magnetic field resulting from the passage of the current and surrounding its path must disturb in some manner the molecular and atomic activities that are going on within its range in the tissues and fluids through which the current of electricity passes. The amount of this disturbance will depend upon the strength and character of the magnetic stress which makes up this field or, in other words, upon the strength and nature of the electric current.

A constant uni-directional current will create a magnetic field of constant polarity and of uniform tension. A uni-directional current, but of varying strength, will create a corresponding magnetic field, pulsating or varying in intensity. While an alternating current will be attended by a magnetic field alternating in polarity with a frequency corresponding to the alternations of the electric current and of an intensity varying in degree with the strength of that current.

We have found that the most noticeable physiological response to an electric current obtained from living animals is that resulting from sudden and wide differences of

potential. We would naturally expect, therefore, that a magnetic field with rapidly reversing polarity and sudden variations in its intensity would produce more noticeable results in a living organism than would a more uniform or constant field.

Careful scientific observation and record of the relation of magnetic stress to physiological action, either in vegetable or animal structure, separate from the effects produced by the passage of the current of electricity itself has been attempted by few. What has been done so far has led to contradictory conclusions. Experiments have for sometime been carried on in this laboratory with the view of gaining some exact knowledge of the amount of change in ordinary life processes that can be brought about by the modifying influences of various forms of magnetic stress.

These experiments were commenced more than two years ago in this laboratory upon man and growing animals by subjecting them for a considerable length of time to the influence of alternating magnetic fields.

This was done by constructing a solenoid three feet in diameter, of number 10 underwriters wire, and with a sufficient number of turns so that a current strength of five amperes produced an average of sixty-five C.G.S. lines for each square inch of space in a plane cross-sectioning the space within the coil. Both for convenience and to determine the value of what we already have at hand, I used the current from a Thompson & Houston alternating dynamo employed for electric lighting, to excite the coil, or solenoid. This dynamo makes 124 cycles per second or 248 alternations. So that the magnetic field or stress in the space enclosed by the coil changed its polarity with this frequency. Whatever occupied this space

therefore was subjected to this rapidly reversing and varying magnetic stress.

The first series of experiments was made with the view of determining the influence of this magnetic field on the metabolism of tissue as determined by the output of urea. Three subjects were chosen. Two of them healthy young men, students of medicine, and the other a man of thirty-eight years of age who had for two years been suffering from paralysis agitans, but who, aside from this nervous affection, was in fair health. The diet was regulated in amount and variety in each case for a week previous to subjecting them to the magnetic action, and a daily estimate was made of the amount of urea excreted. Then for a week's time without change of diet or manner in living in any other respect each one of the three subjects was placed within the solenoid, comfortably outstretched upon a platform, and remained there for two hours each day, their bodies pervaded by the alternating magnetic stress of the average strength above mentioned. During this week also a daily estimate of the quantity of urea was made, and it was found that in all three cases there was a daily increase of about 10 per cent. in the amount eliminated during the period in which the subject was in the magnetic field. No other effects were noticed that could be detected by this method of observation. There was no apparent change in the depth or frequency of respirations nor in the strength nor frequency of the pulse or arterial tension; though it is possible that had more delicate or exact methods of testing for such changes than the unaided eye and touch been employed, some difference in these functions would have been observed. The subjects were conscious of no change in sensation or motive power except that the patient with paralysis agitans

claimed that the period spent within the coil had a soothing and quieting effect upon him and that the muscular tremor which attended his disease was for several hours after each exposure much less violent.

The next series of experiments was with growing animals to determine the effect, if any, of the alternating magnetic stress in retarding or accelerating their growth. Experiments of this nature also have been carried on at the laboratory almost continuously for the past two years.

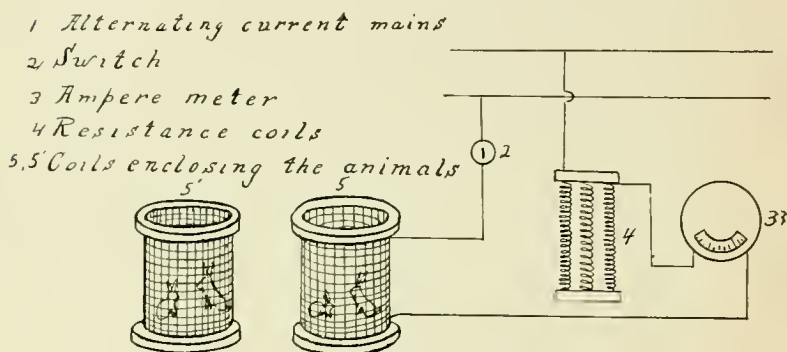


Fig. 50.

Some of the time the animals used were rabbits and at other times guinea pigs. As soon as one or more litters of young rabbits or guinea pigs were old enough to be separated from their mothers, they were divided into two bunches as nearly alike in age and weight as possible, and were carefully weighed. The two bunches were placed in conditions of living in all respects similar except that from five o'clock in the evening until midnight one bunch was placed in a cage (Fig. 50) made of the kind of wire above mentioned through which an alternating five ampere current, with the frequency of alternations above mentioned was passing, and the other bunch was placed in an exactly similar coil which was not

connected with the current circuit. This plan was pursued with each group of animals selected until they had reached their full growth, or from six to twelve weeks, according to the age of the animals at the commencement of the experiment. The laboratory notes contain the weekly record of the weight of each of the groups of animals experimented upon in this manner. The interesting conclusion that has been reached so far from these experiments, which are still in progress, is that the group of animals immersed in the alternating magnetic field without exception began, after the first week, to outstrip the other group in weight, and a gain of from eighteen to twenty-four per cent. in favor of the animals within the magnetic field was observed each succeeding week until they neared the period of full development, at which time the weekly gain was less. During the two years in which these experiments have been going on, ten separate groups of animals have been used either in the magnetic field or as controls, each group containing from three to five animals, and uniformly those placed in the magnetic field gave evidence for the first few weeks of accelerated nutritive action. In the case of two of the groups, when the experiment was continued beyond eight weeks, the curve of increase shown by the magnetized animals, which until eight weeks ran twenty per cent. higher than that of the other group, gradually declined and at the end of the twelfth week their weight had fallen a little below that of the other group.

It is an interesting fact that the janitor who has charge of these animals and is a shrewd observer, but without knowledge as to the purpose of the experiment, called our attention to the fact that the group of animals that was placed within the magnetic field spent much more time in sleep during the day time, that is when the current was

withdrawn, than did the other group, but in no other respect except the increase in weight did he nor we notice any difference in their appearance or conduct.

As far as these experiments go they appear to show that alternating magnetic stress is in some way related to a quickened metabolism of tissue; that magnetic energy goes through some transformation and appears as physiological energy.

These results are very similar to those reported by d'Arsonval and others as resulting from what that observer has termed auto-conduction brought about by high-tension high frequency currents and as the apparatus employed by d'Arsonval is not unlike that which we have employed in these experiments, although the description of d'Arsonval's experiments was not published until some months after we had begun those we have been describing, it is not improbable the effects we have observed are due to the same cause. There is this difference to be noted, however, that while the currents employed by d'Arsonval were of the high-potential and high-frequency character, the current employed by us was of only 52 volt pressure and the frequency of alternations but 248 per second.

## THE THERMO-ELECTRIC GENERATOR.

(T. 419, 425.)

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In 1822 it was discovered that an electric current could be generated by heating the point of contact of two dissimilar metals. Later it was found that if a number of points of union of such metals were so arranged that alternate junctions could be heated the E. M. F. would be increased. This is therefore a method whereby heat is directly transformed into electric energy in the form of a direct current. The accompanying figure represents a thermo-electric generator employing these principles which is capable of producing electric currents of sufficient strength and intensity for various practical applications. The heat furnished by the combustion of gas flowing from an ordinary gas burner and the parts other than the points of junction of the dissimilar metals are kept cool by allowing a stream of water to flow through the apparatus. The generator tested in this laboratory has an E. M. F. of 6 volts and furnishes a current somewhat exceeding 3 amperes. The output of energy is subject to very slight variations. The following are some of the therapeutic applications to which such a source of electric energy furnishing a current of this nature would be adapted:

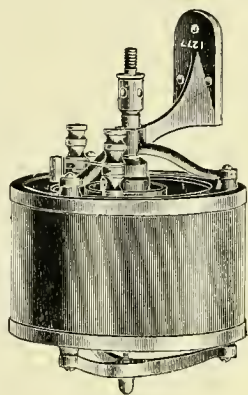


Fig. 51.

1. It would heat electric cauteries having comparatively fine wires, or would light some of the smaller varieties of medical exploring lamps.

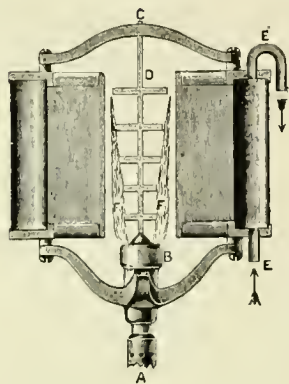


Fig. 52.

2. It could be used to excite a medical induction coil.

3. By employing a good low voltage electric motor it could be used to run various mechanical devices needed in the physician's or dentist's office.

Owing to the low E. M. F. of the current it could not be conveyed through the tissues of the body so as to do effectively any of the work which we have discussed under the head of electrolysis, phoresis, or the physiological action of the direct current.

## ELECTRO-THERMIC GENERATORS.

We have considered (p. 56) electricity as a source of heat for heating the electro-cautery. It was there stated that whenever electricity is expended in overcoming resistance it reappears in the form of heat or radiant energy. Many applications of this principle may be made in therapeutics in addition to that of the electro-cautery.

When a constant source of electric energy is conveniently at hand as is the case in many hospitals as well as in private houses at the present time, a steady and equable application of heat may be made to a patient, when it is

needed, by some suitable arrangement for transforming electric energy into heat. The accompanying figure illus-

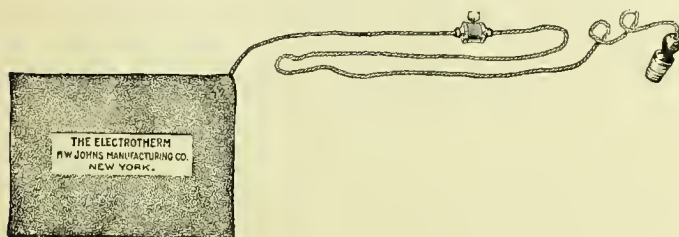


Fig. 53.

trates one of these in the form of a pliable and adjustable pad. It consists of two sheets of asbestos with wire imbedded in them enclosed in a cover of flannel. When attached by conducting wire cords to the socket of an incandescent lamp the temperature of the pad can be raised to any degree desired and there maintained for any length of time. An appliance for this purpose can utilize either an alternating or direct current.



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Baltimore, Md.

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C. C. COLE,  
Iowa College of Law.

I have examined with care Dwyer's "Cases on Private International Law", and find them judiciously selected and edited. The author has succeeded in presenting in a small compass many important decisions in which the leading doctrines of this branch of the law are exhibited and applied in a manner to make the book useful alike to the student and to the practitioner. I trust the work will meet with the favorable reception it deserves.

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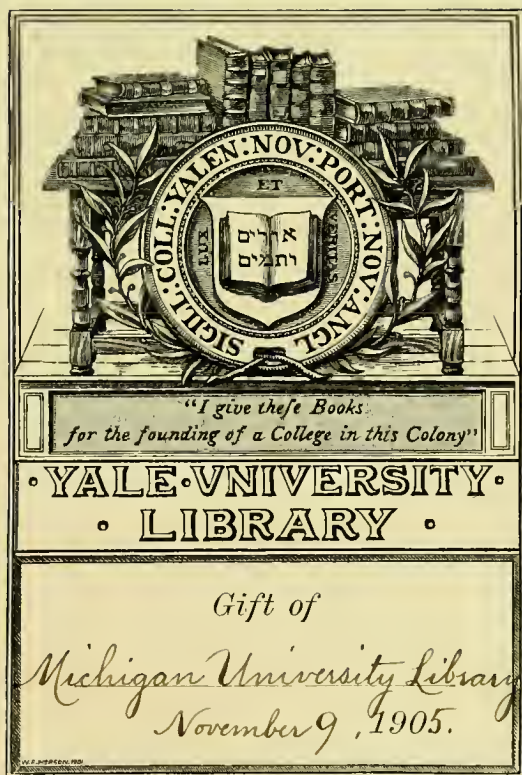
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